

ER 8295

COMPONENTS IRRADIATION TEST NO. 17  
RESISTANCE THERMOMETERS  
AT  
LIQUID HYDROGEN TEMPERATURES

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## FOREWORD

This report is submitted to the Astrionics Laboratory of the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama, in accordance with the requirements of Task Order No. ASTR-LGC-30 of Contract No. NAS 8-5332. The report is one of a series describing radiation effects on various electronic components. This particular report concerns three types of platinum resistance thermometers and one type of carbon resistance thermometer at liquid hydrogen temperatures.

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## 1.0 SUMMARY

Specimens of resistance thermometers were subjected to a nuclear radiation environment while immersed in liquid hydrogen. The specimens irradiated were:

No.	Item	Type	Manufacturer
2	Thermometer, Platinum	134EB400	Rosemount
2	Thermometer, Platinum	150BH	Rosemount
2	Thermometer, Platinum	T4082 A4H-7	Trans-Sonics
2	Thermometer, Carbon	S130	Gulton

Measurements were made to determine the effect of the radiation on the resistance of the thermometers.

Test results indicated:

For the platinum resistance thermometers

- (1) A combined radiation dose of  $1 \times 10^{15} \text{ n/cm}^2$  and  $2.3 \times 10^7 \text{ r}$  at  $\text{LH}_2$  temperatures (20 to  $23^\circ\text{K}$ ) had no significant effect on the temperature indication of the thermometers.

For the carbon resistance thermometers

- (1) A combined radiation dose of  $1 \times 10^{15} \text{ n/cm}^2$  and  $2.3 \times 10^7 \text{ r}$  at  $\text{LH}_2$  temperatures (20 to  $23^\circ\text{K}$ ) changed the temperature indication of the thermometers by as much as  $0.2^\circ\text{K}$ .

## 2.0 INTRODUCTION

The experiment described in this report is the seventeenth irradiation of electronic components and is the twenty-second in a series of radiation effects tests on electronic equipment, circuits, and components contemplated for use on a nuclear space vehicle. Since the use of equipment on this vehicle is contingent upon its ability to withstand the nuclear environment, the Astrionics Laboratory of the Marshall Space Flight Center has undertaken to assure that Government furnished or specified equipment will survive this environment. The equipment is to be subjected to the expected nuclear environment as simulated at the Georgia Nuclear Laboratories. Measurements made on the equipment during the irradiation will describe its radiation tolerance.

The subjects of this test are the Rosemount type 134EB400 platinum resistance thermometer, the Rosemount type 150BH platinum resistance thermometer, the Trans-Sonics type T4082 A4H-7 platinum resistance thermometer and the Gulton type S130 carbon resistance thermometer.

### 3.0 TEST PROCEDURE

The test specimens were supplied by the Astrionics Laboratory of the Marshall Space Flight Center. The specimens were subjected to a total gamma dose of  $2.31 \times 10^7$  r and a total integrated neutron flux of  $1.02 \times 10^{15}$  n/cm<sup>2</sup> while immersed in a pressure controlled liquid hydrogen environment. The source of the irradiation was the Radiation Effects Reactor at the Georgia Nuclear Laboratories.

Before, during, and after the irradiation measurements were made on all test specimens to determine the resistance of each. Other measurements made were those necessary to define the nuclear and temperature environments.

#### 3.1 TEST SPECIMENS

The specimens tested are listed in Table 1. All were new units and had been subjected only to receiving inspection. Instrumentation circuitry and mounting hardware were provided by Georgia Nuclear Laboratories.

##### 3.1.1 Specimen Mounting

The specimens were mounted on a wire truss structure designed to allow free circulation of liquid hydrogen around the specimens and to hold the specimens in such positions as to provide equal radiation flux distribution. A copper-constantan thermocouple was mounted adjacent to each specimen to provide corroborative data, and neutron foils were placed to monitor the neutron flux. Figures 1 and 2 show the mounted specimens and the liquid hydrogen container in which they were placed. The container was then mounted in the test chamber on the primary car of the GNL Mobile Liquid Hydrogen System. The primary car is shown in Figure 3. For the irradiation the car was positioned so that the test chamber was directly adjacent to the reactor. Figure 4 shows a schematic cross section through the test chamber as seen from the reactor.

## 3.2 LIQUID HYDROGEN ENVIRONMENT

### 3.2.1 Control And Measurement

The vapor pressure of the liquid hydrogen, and thus its temperature, was controlled by manipulating a valve in the vent line leading from the  $\text{LH}_2$  Dewar. The pressure was monitored by a Texas Instruments Precision Pressure Indicator, Model 141A. The output of this indicator was recorded in digital form by a Friden Flexowriter. A schematic diagram of the control and measurement system is shown in Figure 5.

The liquid hydrogen in the Dewar containing the specimens was replenished as necessary during the test from the large storage tank on the primary car.

## 3.3 RADIATION ENVIRONMENT

### 3.3.1 Control And Measurement

The nuclear radiation was controlled by controlling the power of the reactor. Four reactor power settings were used during the test:

100 kW, 500 kW, 1 MW and 3 MW.

The radiation environment was evaluated with neutron sensitive foils and gamma ionization chambers placed near the test specimen locations as shown in Figures 4 and 6.

All foils were processed by standard procedures to arrive at the incident neutron flux. A tabulation of the results for foils located on the "dome" and those located inside the "dewar" is given in Table 2. Consideration of the geometrical parameters and the liquid hydrogen attenuation factors indicates good agreement between the dome and dewar fluxes. The data from Table 2 is presented in Figure 7.

The solid line in Figure 7 represents the best estimate of the spectral shape in the liquid hydrogen environment. The effects, if any, of liquid hydrogen temperatures on the sensitivity of the foils are not known. However, inspection of the data points in Figure 7 indicates no appreciable difference in spectral shape inside and outside the dewar. The spectral shape in air with no shielding at this particular location in the reactor building has been previously determined and is shown as a dashed line in Figure 7.

The gamma ionization chamber temperatures were monitored to insure data integrity at low temperatures. Previous experiments have indicated no ion chamber sensitivity changes over the range of  $-65^{\circ}\text{F}$  to  $+170^{\circ}\text{F}$ . Indicated ion chamber temperatures in this experiment were approximately  $-10^{\circ}\text{F}$ .

A compilation of neutron and gamma data is given in Table 3 which represents the radiation environment to which the test specimens were subjected. Figure 8 shows the reactor operation time versus power for this test.

### 3.4 TEST SPECIMEN MEASUREMENTS

#### 3.4.1 Instrumentation

A Mueller Temperature Bridge (L & N 8067) was used to measure the resistance of each specimen. The thermocouple outputs were measured by a Cimron 7500 DVM. The instrumentation circuits are shown in Figure 9.

#### 3.4.2 Procedure

The procedure for making a set of measurements was as follows:

- (a) The  $\text{LH}_2$  Dewar containing the specimens was fully charged from the  $\text{LH}_2$  Storage Tank. The storage tank pressure was allowed to stabilize

at about 45 psia prior to the test. The pressure was maintained throughout the test.

- (b) The vent control valve was manipulated to provide the desired  $\text{LH}_2$  vapor pressure (temperature). The pressure was adjusted such that an always decreasing pressure was maintained. This procedure circumvented any possibility of a super-cooled liquid.
- (c) Resistance of the first specimen was measured in the normal position with the Mueller Temperature Bridge and recorded manually.
- (d) The output of the corresponding thermocouple was recorded by the Friden Flexowriter.
- (e) The output of the Precision Pressure Indicator was recorded by the Friden Flexowriter.
- (f) Resistance of the first specimen was measured in the reverse position with the Mueller Temperature Bridge and recorded manually.
- (g) Steps (c), (d), (e) and (f) were repeated for each of the other specimens in turn.

Prior to the irradiation several sets of data were taken at temperatures varying from about  $20.3^\circ\text{K}$  to about  $23.1^\circ\text{K}$  to establish baseline data for the test. During the irradiation one set of data was taken at a reactor power of 100 kW, another set at 500 kW, another set at 1 MW, and eleven sets at 3 MW. All of these data were taken at  $\text{LH}_2$  temperatures of  $20.7^\circ\text{K}$  or below. Four sets of post-irradiation data were taken at  $\text{LH}_2$  temperatures between  $20.3^\circ\text{K}$  and  $23.2^\circ\text{K}$ . The post-irradiation measurements were made immediately after the reactor was shut down.

#### 4.0 METHOD OF DATA ANALYSIS

A large scale calibration curve was carefully prepared for each of the thermometer specimens from the calibration table furnished with the specimen. Where it was necessary to interpolate between widely separated calibration points an  $R_T/R_0$  versus temperature table\* was used to locate the curve. ( $R_T$  is the element resistance at temperature T in  $^{\circ}\text{C}$ , and  $R_0$  is the element resistance at  $0^{\circ}\text{C}$ .)

A large scale calibration curve was also prepared for the Precision Pressure Indicator from manufacturer's calibration data and Table 9.24, page 298, of Cryogenic Engineering, Russell B. Scott, Van Nostrand Co., Inc., which gives  $\text{LH}_2$  vapor pressure-temperature data.

For a given time and specimen the mean resistance of the specimen was calculated from normal and reverse measurements made in the shortest possible time span. This mean resistance was then used to enter the applicable calibration curve and determine the corresponding temperature. A precision  $\text{LH}_2$  pressure measurement made simultaneously with the specimen resistance measurements was used to enter the pressure-temperature curve to determine the  $\text{LH}_2$  temperature.

An analysis of random errors in the reduced data is shown in Table 4.

The temperature indicated by the thermometer specimen minus the  $\text{LH}_2$  temperature was designated the "specimen error". These errors were then plotted versus  $\text{LH}_2$  temperature. It was reasoned that radiation effects, if any, would be indicated by changes in these errors.

\*TABLE III  $R_T/R_0$  Versus Temperature ( $^{\circ}\text{C}$ ) For Typical Pure, Annealed, Strain-Free Platinum Resistance Temperature Sensor ( $-260$  to  $+820^{\circ}\text{C}$ ) From Rosemount Engineering Company Bulletin 9612.

Since the thermocouples had not been calibrated under the test conditions no comparison could be made between temperatures indicated by the thermocouples and those indicated by the specimens. Instead, the output of each thermocouple was plotted against the temperature of the  $\text{LH}_2$  as determined from a simultaneous measurement by the Precision Pressure Indicator. These plots drew attention to, and helped explain, some apparent discrepancies and changes which appear in the "specimen error" plots. These will be discussed in Section 5.0.

Copies of the original and reduced data are on file in the Georgia Nuclear Laboratories.

## 5.0 TEST DATA AND DISCUSSION OF RESULTS

The test data have been presented herein in graphical form. One of the figures (Figure 26) shows specimens' errors versus integrated neutron flux. The abscissa scale on this figure is accumulated neutrons/cm<sup>2</sup> greater than 0.5 MeV. However, it is important to remember that the radiation exposure was a combination of neutrons and gamma rays and that each may contribute, in varying degrees, to the degradation of a component's parameter. Consequently, in Figure 26, the coincident accumulated gamma dose (r) is also indicated at those points where changes in radiation rate occurred.

### 5.1 THERMOCOUPLE DATA

The thermocouples used in the test had not been calibrated at test conditions, therefore, no direct comparison could be made between temperatures indicated by the thermocouples and those indicated by the thermometer specimens. However, since thermocouples are not affected by nuclear radiation, their outputs relative to the LH<sub>2</sub> temperatures obtained from the Precision Pressure Indicator should give some indication of the reliability of the LH<sub>2</sub> temperature measurement system. Consequently, the outputs of all thermocouples were plotted versus LH<sub>2</sub> temperatures obtained from the pressure indications. These data are shown in Figures 10 through 17. In these figures those "during irradiation" data points numbered 1 were taken at 100 kW reactor power, those numbered 2 were taken at 500 kW, those numbered 3 were taken at 1 MW, and all others were taken at 3 MW.

An examination of the data in Figures 10 through 17 revealed the following salient points:

- (a) In the pre-irradiation data the output curves showed an upturn at pressure indicated LH<sub>2</sub> temperatures in the vicinity of 20.3°K.

- (b) During the irradiation there was a gradual increase in thermocouple outputs at a constant pressure indicated  $\text{LH}_2$  temperature of about  $20.6^\circ\text{K}$ .
- (c) The post-irradiation data showed greater thermocouple outputs at a given temperature than did pre-irradiation data.

These observations led to the following conclusions:

- (a) In the pre-irradiation data the pressure indicated  $\text{LH}_2$  temperatures in the vicinity of  $20.3^\circ\text{K}$  were not completely accurate. This may have been due to the fact that in this temperature region the pressure in the  $\text{LH}_2$  Dewar was near atmospheric, and air or helium, or both, may have diffused into the Dewar via the vent line, thus invalidating the  $\text{LH}_2$  vapor pressure-temperature relationship.
- (b) The gradual increase in the thermocouples outputs during irradiation at a near constant  $\text{LH}_2$  temperature indicated either an increasing reference ice bath temperature or a shift in the zero point of the Precision Pressure Indicator. The ice bath temperature had not been monitored during the test so there was no way to verify a change. However, the zero point on the Precision Pressure Indicator was checked about four days after the end of the irradiation and was found to have shifted sufficiently to cause the indicated  $\text{LH}_2$  temperatures to have an error of  $-.04^\circ\text{K}$ . This error was in the wrong direction to explain the gradually increasing thermocouple outputs. Therefore, it is believed that the difference between the pre-irradiation and post-irradiation outputs of the thermocouples at a given temperature was due to a slow warming of the ice bath during the test. An increase of about  $.25^\circ\text{K}$  (which is not unreasonable) in the ice bath temperature would account for a

change of about  $1.6^{\circ}\text{K}$  in thermocouple indications at  $\text{LH}_2$  temperatures.

The Precision Pressure Indicator had been located on the rear of the primary car of the Mobile Liquid Hydrogen System and was shielded by the large  $\text{LH}_2$  Storage Tank. However, this instrument contains photodiodes in its balancing circuits, and photodiodes are affected by both radiation rate and radiation dose (Reference - Components Irradiation Test No. 16). Therefore, the temperature indication of this instrument during the irradiation may have been in error by a slightly greater amount, especially near the end of the irradiation, than the  $-.04^{\circ}\text{K}$  error determined four days after the end of the irradiation.

## 5.2 PLATINUM RESISTANCE THERMOMETERS

The data obtained on the specimens tested are shown in Figures 18 through 23. The upturn of the pre-irradiation error curve at about  $20.3^{\circ}\text{K}$  in each of the figures is believed due to error in the pressure indicated  $\text{LH}_2$  temperature in this temperature region as discussed above. The gradual change in a more positive direction of the "during irradiation" data points can be explained by a gradual upward shift of the zero point of the Precision Pressure Indicator. The greater errors shown "during irradiation" than "post-irradiation" at a given temperature may be explained by postulating a larger zero shift in the Precision Pressure Indicator during irradiation than after irradiation ceased. Radiation rate effects on the photodiodes could account for such larger error.

In Figures 18 through 23 a dashed line shows the post-irradiation data corrected for the net error of the Precision Pressure Indicator as determined four days after the test. A comparison of the pre-irradiation data with the corrected post-irradiation data shows no significant radiation effects on these specimens.

### 5.3 CARBON RESISTANCE THERMOMETERS

Figures 24 through 26 show the data obtained on the two specimens tested. In Figures 24 and 25 the "during irradiation" data points at first showed a tendency to increase in the positive direction due to shift in zero point of the Precision Pressure Indicator. However, at data points 5 and 6 radiation damage to the specimens overcame this effect and started a shift in a negative direction. The corrected post-irradiation data showed definite radiation effects on these specimens. Figure 26 shows the errors of each specimen versus integrated neutron flux. Conclusions to be drawn from these figures are that this type thermometer can withstand radiation doses of about  $4 \times 10^{13}$  n/cm<sup>2</sup> and  $4 \times 10^5$  r at LH<sub>2</sub> temperatures without significant damage, but that radiation doses of  $1 \times 10^{15}$  n/cm<sup>2</sup> and  $2.3 \times 10^7$  r at LH<sub>2</sub> temperatures can cause changes in indicated temperatures on the order of 0.1 to 0.2°K.

TABLE 1 TEST SPECIMENS AND TEST CONDITIONS

Description	Number Tested	Test Conditions	Parameter
Thermometer, Platinum Resistance Type 134EB400 Rosemount	2	Nuclear Irradiation At Liquid Hydrogen Temperature	Resistance
Thermometer, Platinum Resistance Type 150BH Rosemount	2	Same As Above	Resistance
Thermometer, Platinum Resistance Type T4082 A4H-7 Trans-Sonics	2	Same As Above	Resistance
Thermometer, Carbon Resistance Type S130 Gulton Industries	2	Same As Above	Resistance

TABLE 2 COMPILATION OF NEUTRON DATA

Foil Type	Threshold Energy $E_T$ (MeV)	Threshold Reaction Cross Section barns	Neutron Flux at 3 MW Dome $n/cm^2/sec > E_T$	Neutron Flux at 3 MW Dewar $n/cm^2/sec > E_T$
—	0.5*	—	—	$2.80 \times 10^{10*}$
S	2.9	0.30	$1.14 \times 10^{10}$	$1.03 \times 10^{10}$
Ni	5.0	1.23	$4.81 \times 10^9$	$3.79 \times 10^9$
Mg	6.3	0.048	$2.51 \times 10^9$	$2.09 \times 10^9$
Al	8.1	0.11	$5.24 \times 10^8$	$4.67 \times 10^8$

\*Extrapolated Value

TABLE 3 NEUTRON AND GAMMA DATA

Position	Gamma Exposure Dose Rate R/Hour	Total Gamma Exposure Dose R	Accumulated Gamma Dose R	Fast Neutron Flux >0.5 MeV $\frac{\text{neutrons}}{\text{cm}^2 \text{-sec}}$	Total For Period $\text{n/cm}^2$	Accumulated $\text{n/cm}^2$	Time Period Hours	Reactor Power MW
IC 55 Dome	$7.69 \times 10^4$	$3.20 \times 10^4$	$3.20 \times 10^4$	$9.33 \times 10^8$	$1.40 \times 10^{12}$	$1.40 \times 10^{12}$	2059- 2124	0.10
IC 55 Dome	$3.64 \times 10^5$	$1.09 \times 10^5$	$1.41 \times 10^5$	$4.67 \times 10^9$	$5.04 \times 10^{12}$	$6.44 \times 10^{12}$	2124- 2142	0.50
IC 55 Dome	$7.44 \times 10^5$	$2.11 \times 10^5$	$3.52 \times 10^5$	$9.33 \times 10^9$	$9.52 \times 10^{12}$	$1.60 \times 10^{13}$	2142- 2159	1.00
IC 55 Dome	$2.27 \times 10^6$	$2.27 \times 10^7$	$2.31 \times 10^7$	$2.80 \times 10^{10}$	$1.01 \times 10^{15}$	$1.02 \times 10^{15}$	2159- 0759	3.00

TABLE 4 RANDOM ERROR ANALYSIS

Kind Of Error	% Error	Error In °K	
		Platinum Thermometer	Carbon Thermometer
Mueller Bridge	± .02	± .002	± .01
Precision Pressure Indicator	± .015	± .001	± .001
Interpolation/Extrapolation Of Thermometer Calibration Curve	—	± .02	± .02
Interpolation Of LH <sub>2</sub> Pressure-Temperature Curve*	—	± .02	± .02
Root Sum Square	—	± .028	± .030

\*Curve Prepared From Table 9.24, Page 298, Of Cryogenic Engineering, Russell B. Scott, Van Nostrand Co., Inc., 1959.

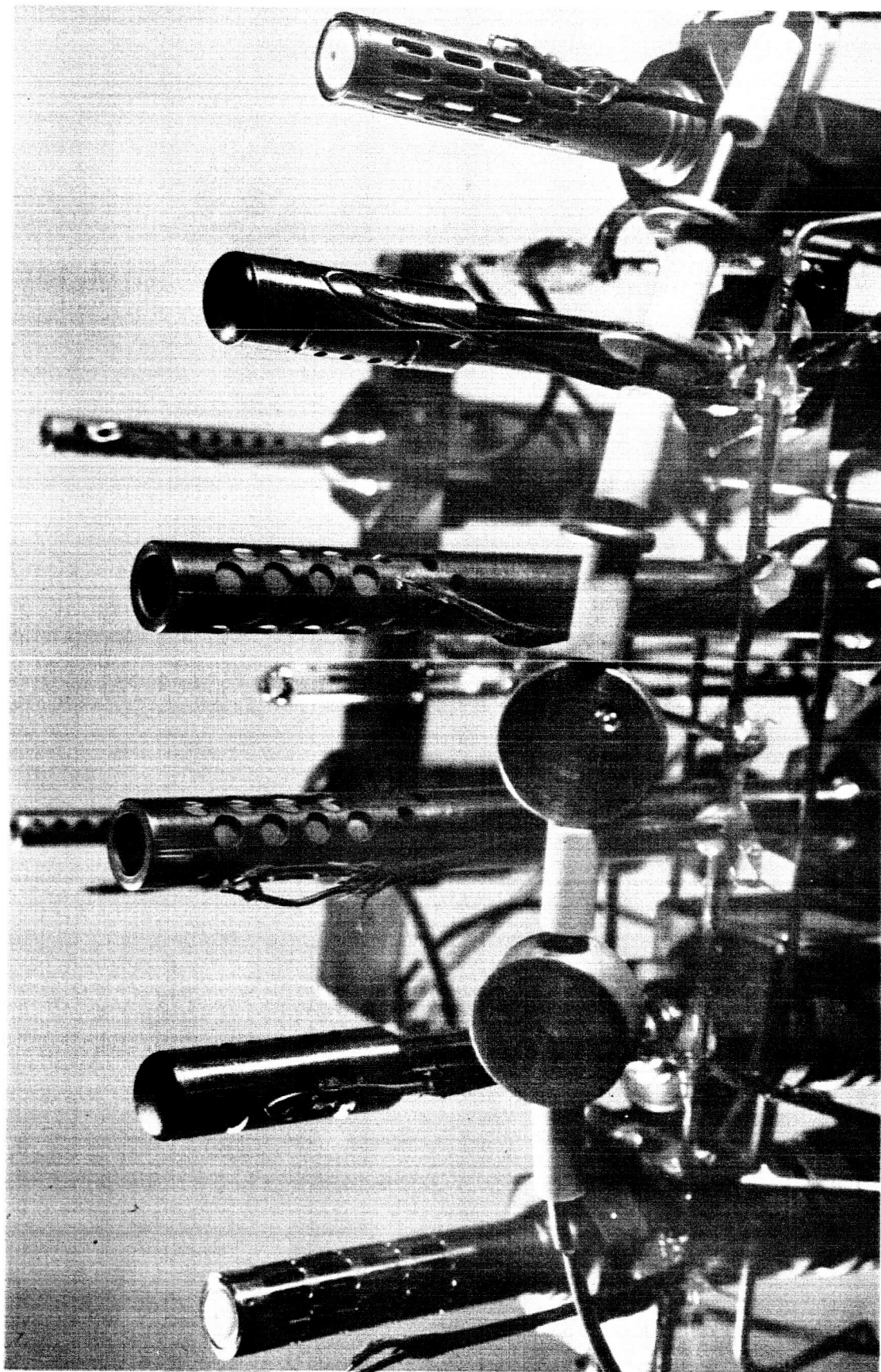


FIGURE 1 CLOSE-UPS OF MOUNTED SPECIMENS

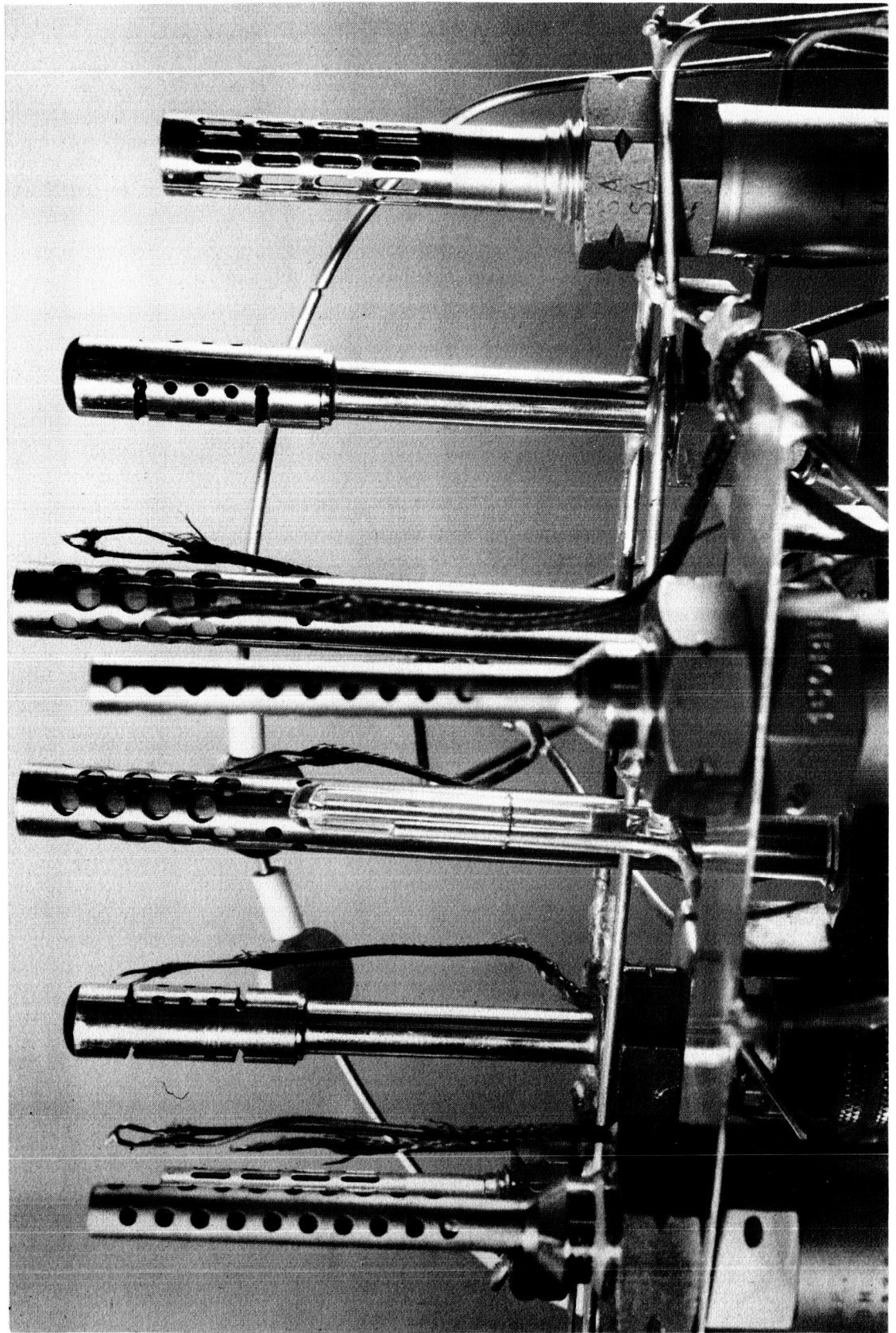


FIGURE 1 (CONTINUED) CLOSE-UPS OF MOUNTED SPECIMENS

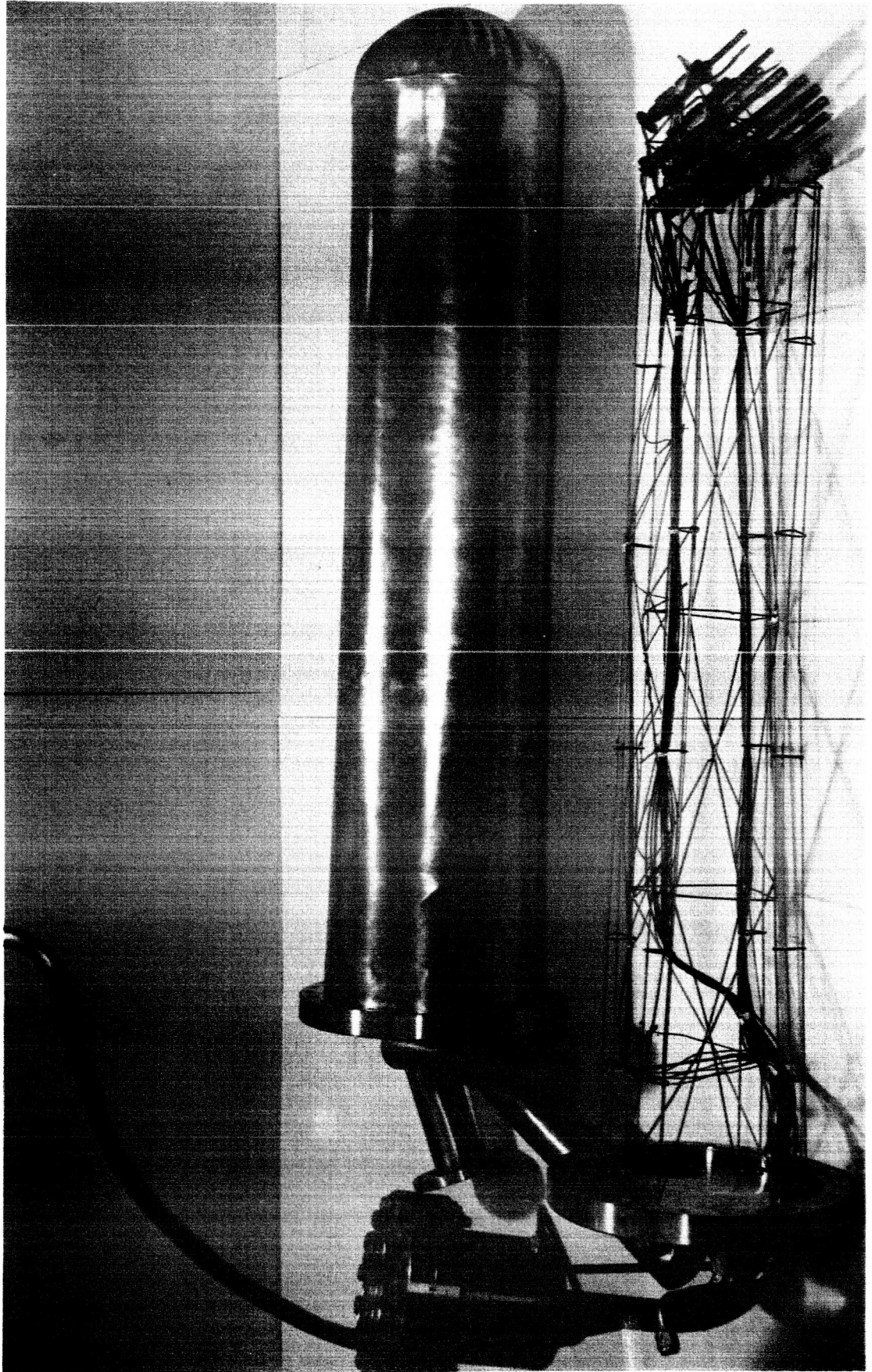
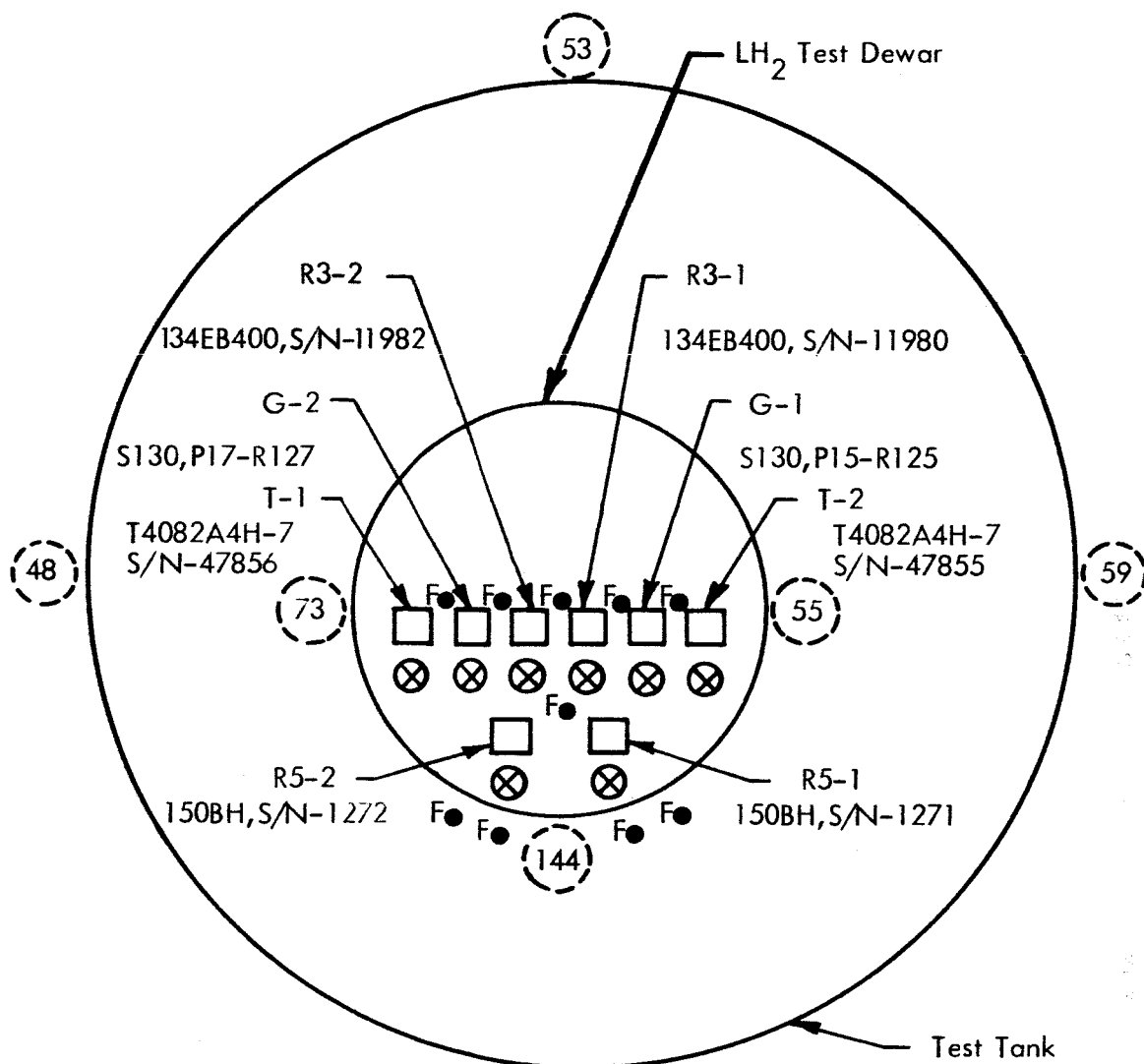


FIGURE 2 MOUNTED SPECIMENS AND LH<sub>2</sub> DEWAR, DISASSEMBLED



FIGURE 3 PRIMARY CAR OF THE MOBILE LIQUID HYDROGEN SYSTEM



Front View As Seen From RER  
(Cross Section)

- — Test Specimens
- ⊗ — Copper-Constantan Thermocouples
- F● — Neutron Foils
- — Ionization Chambers

FIGURE 4 SPECIMEN MOUNTING INSIDE  $LH_2$  TEST TANK

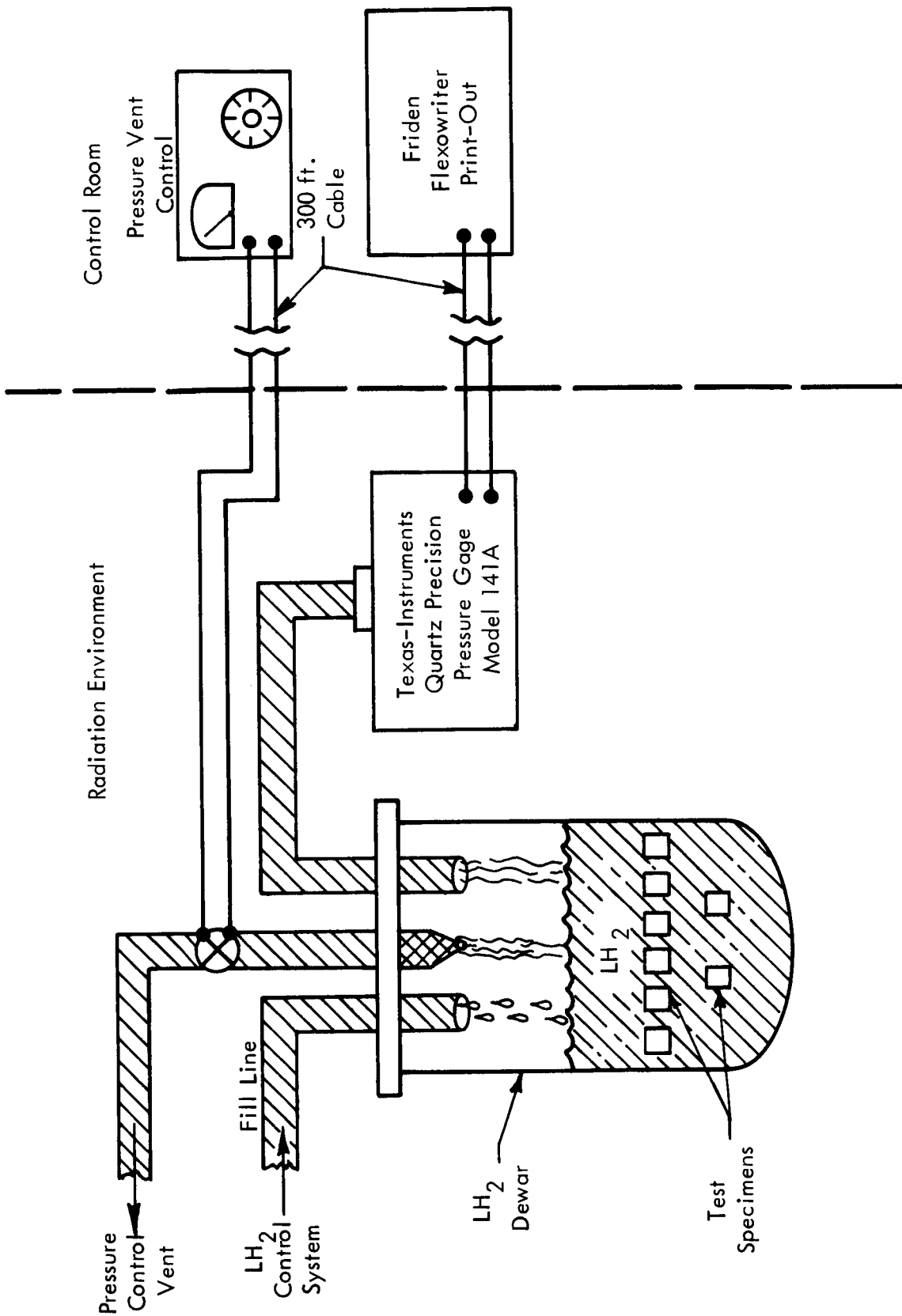


FIGURE 5 LH<sub>2</sub> ENVIRONMENT PRESSURE CONTROL AND MEASUREMENT DIAGRAM

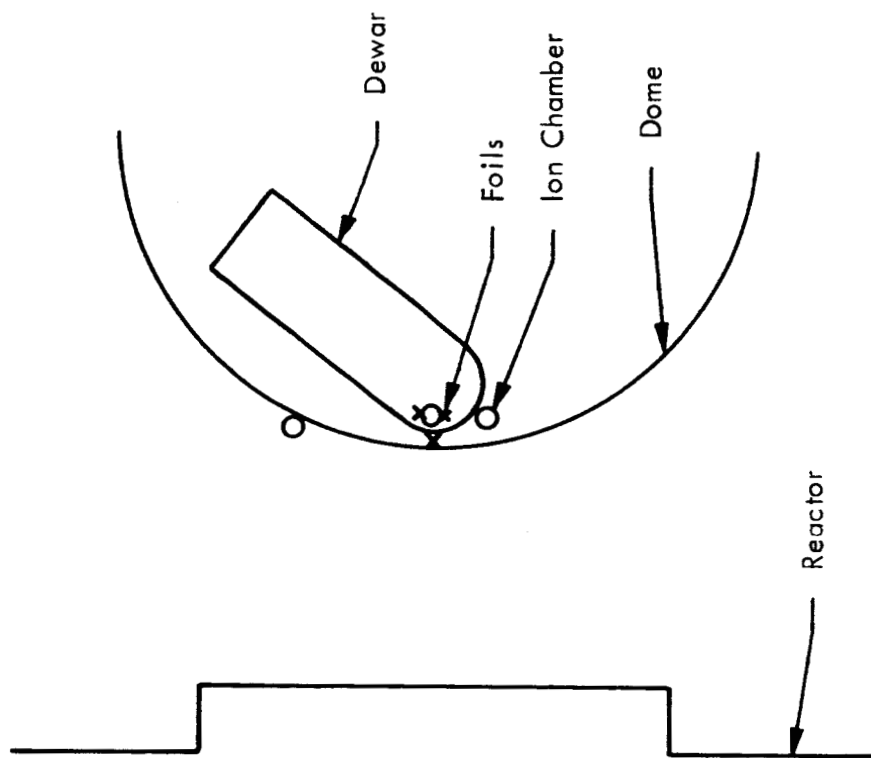


FIGURE 6 FOIL AND ION CHAMBER LOCATIONS (SIDE ELEVATION)

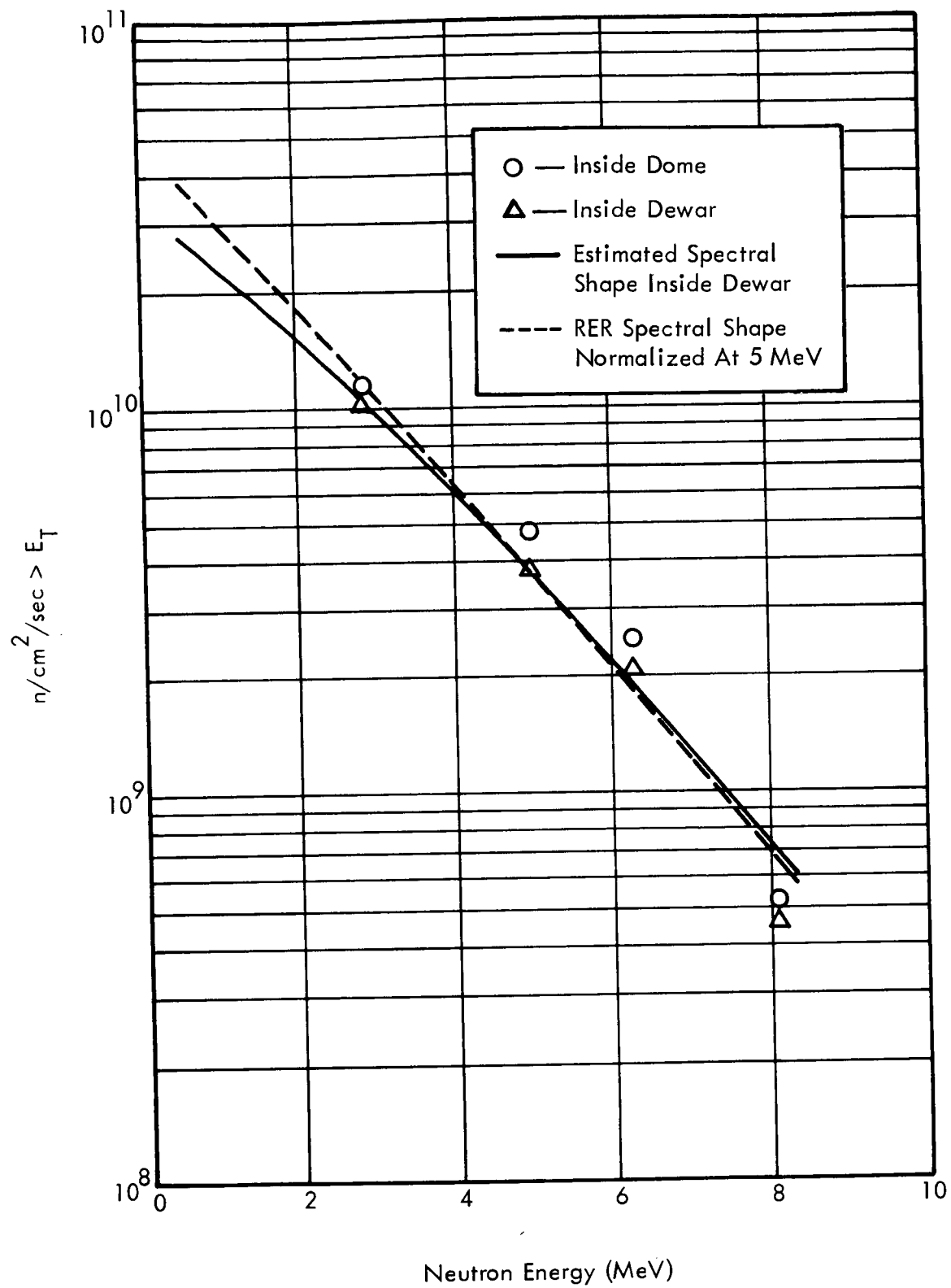


FIGURE 7 NEUTRON SPECTRA

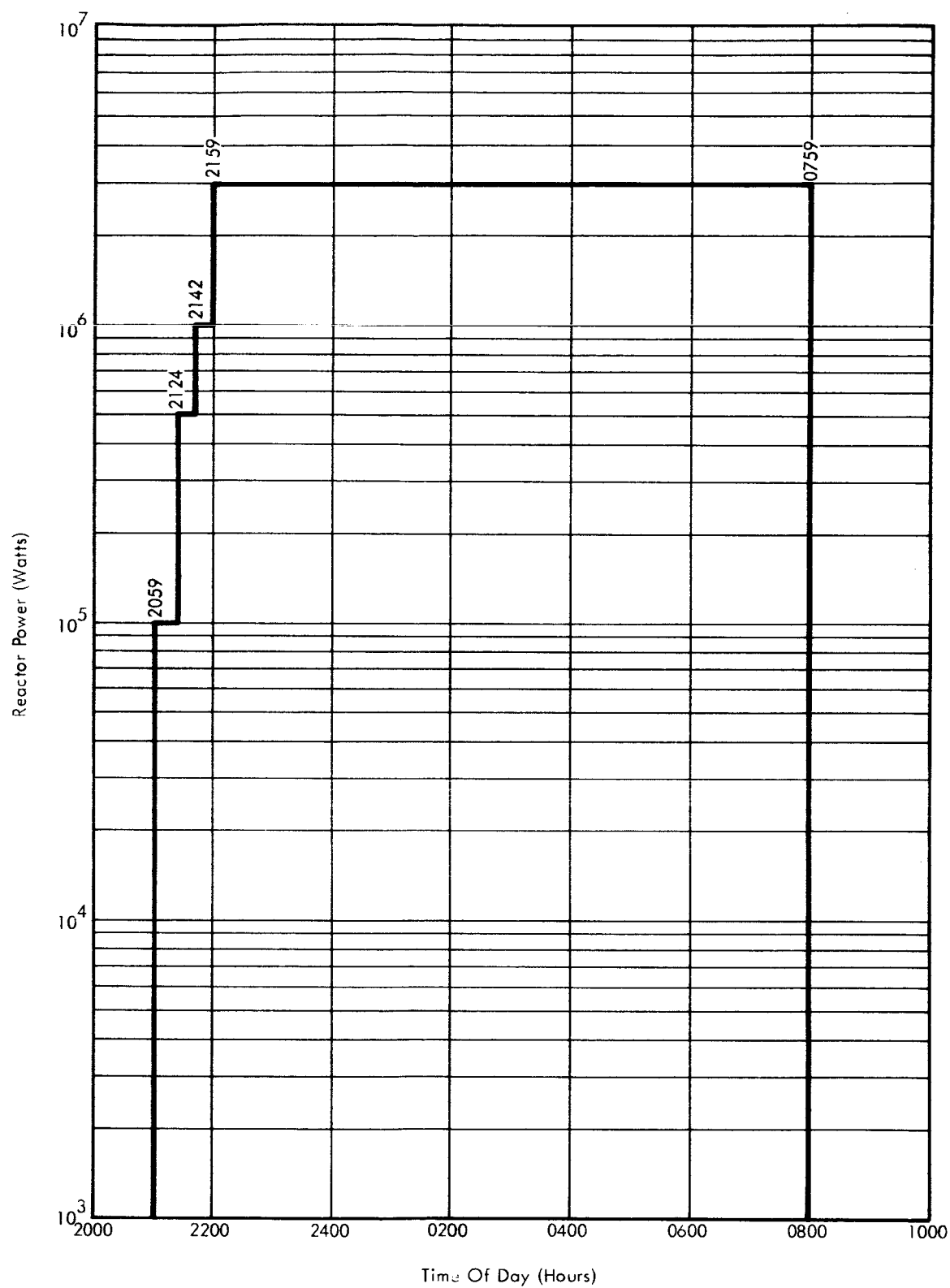


FIGURE 8 RER OPERATION, OCTOBER 7, 1965, AND OCTOBER 8, 1965

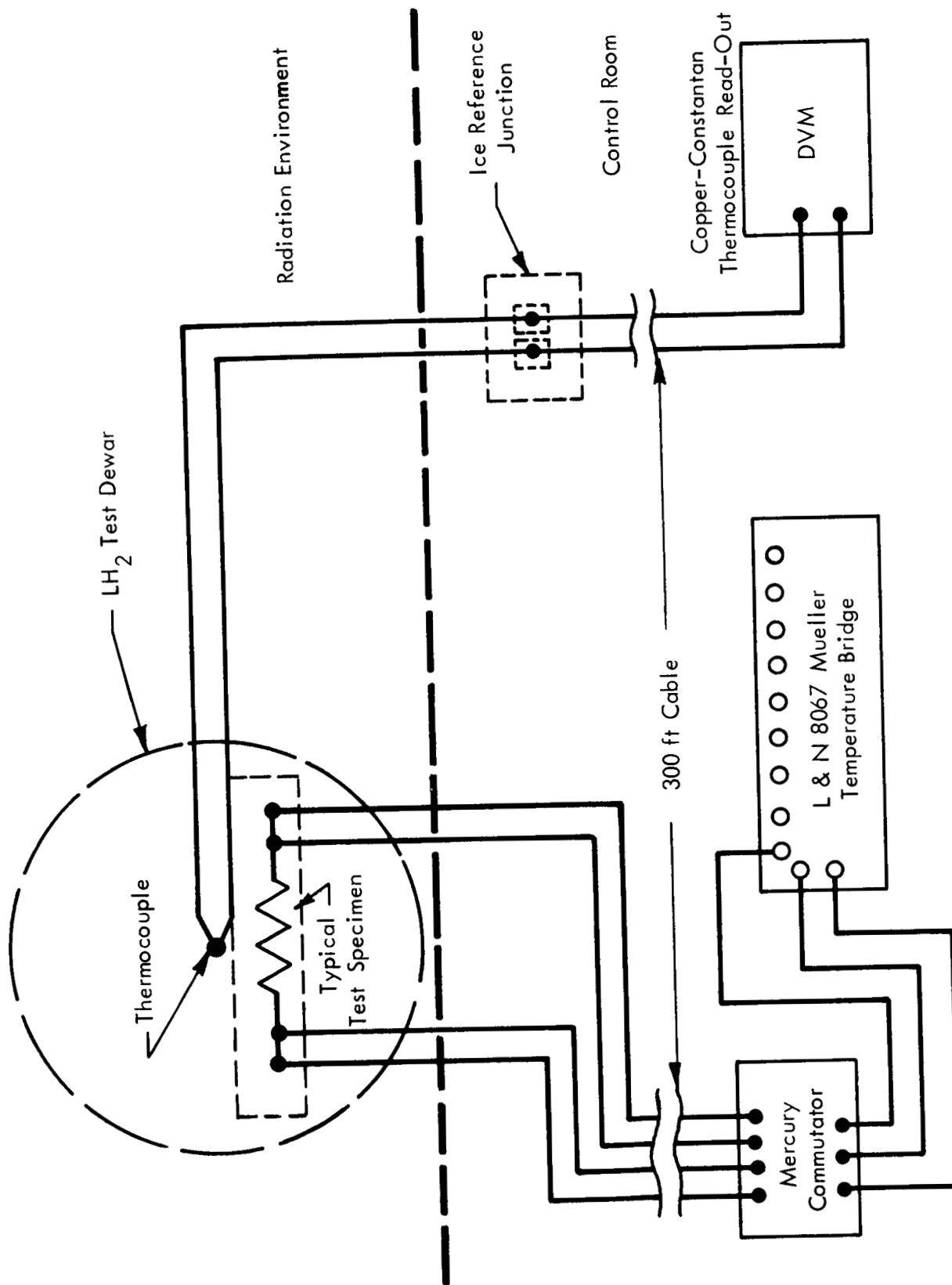


FIGURE 9 RESISTANCE THERMOMETER TEST MEASUREMENT CIRCUIT

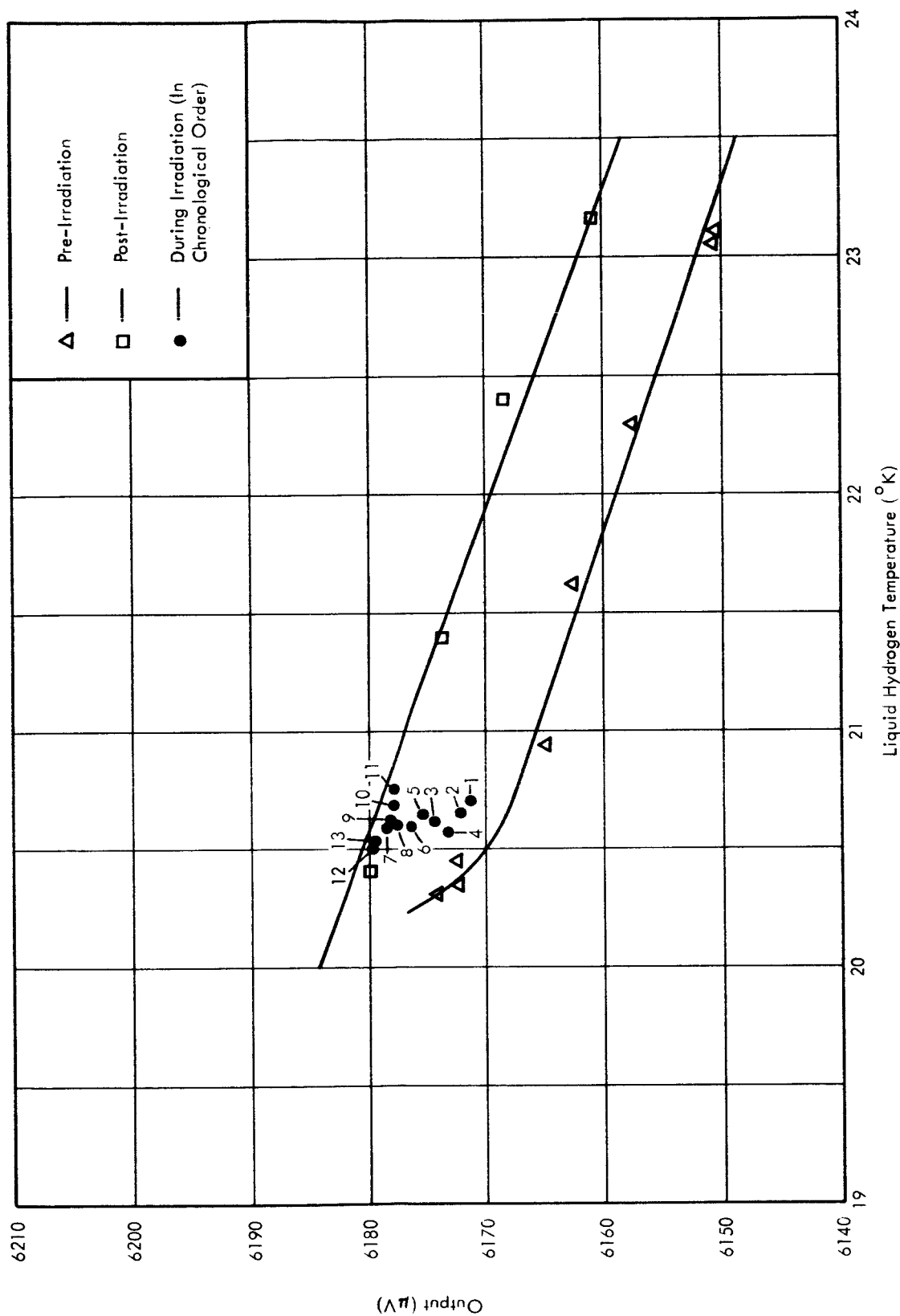


FIGURE 10 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN R3-1 VERSUS LIQUID HYDROGEN TEMPERATURE

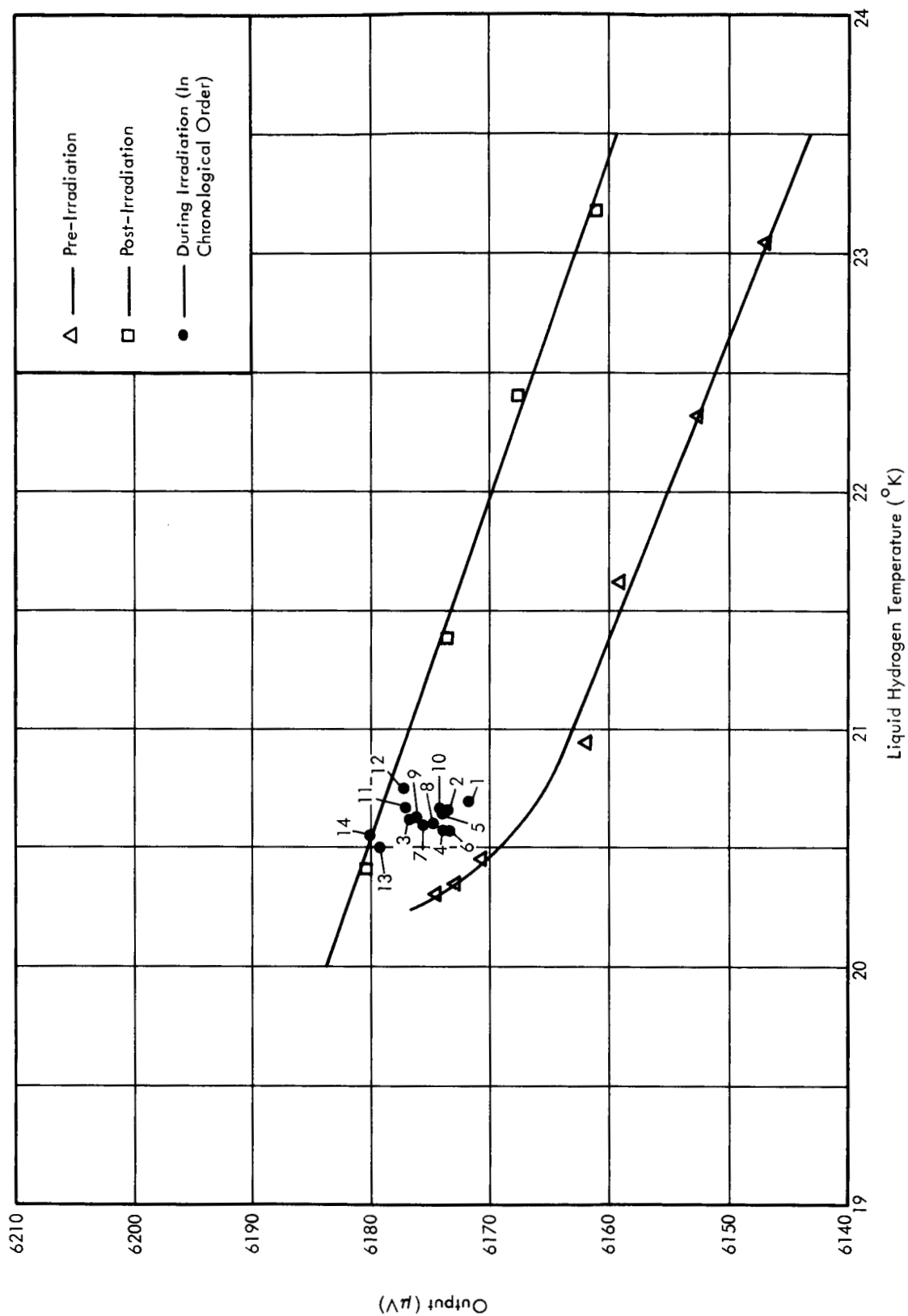


FIGURE 11 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN R3-2 VERSUS LIQUID HYDROGEN TEMPERATURE

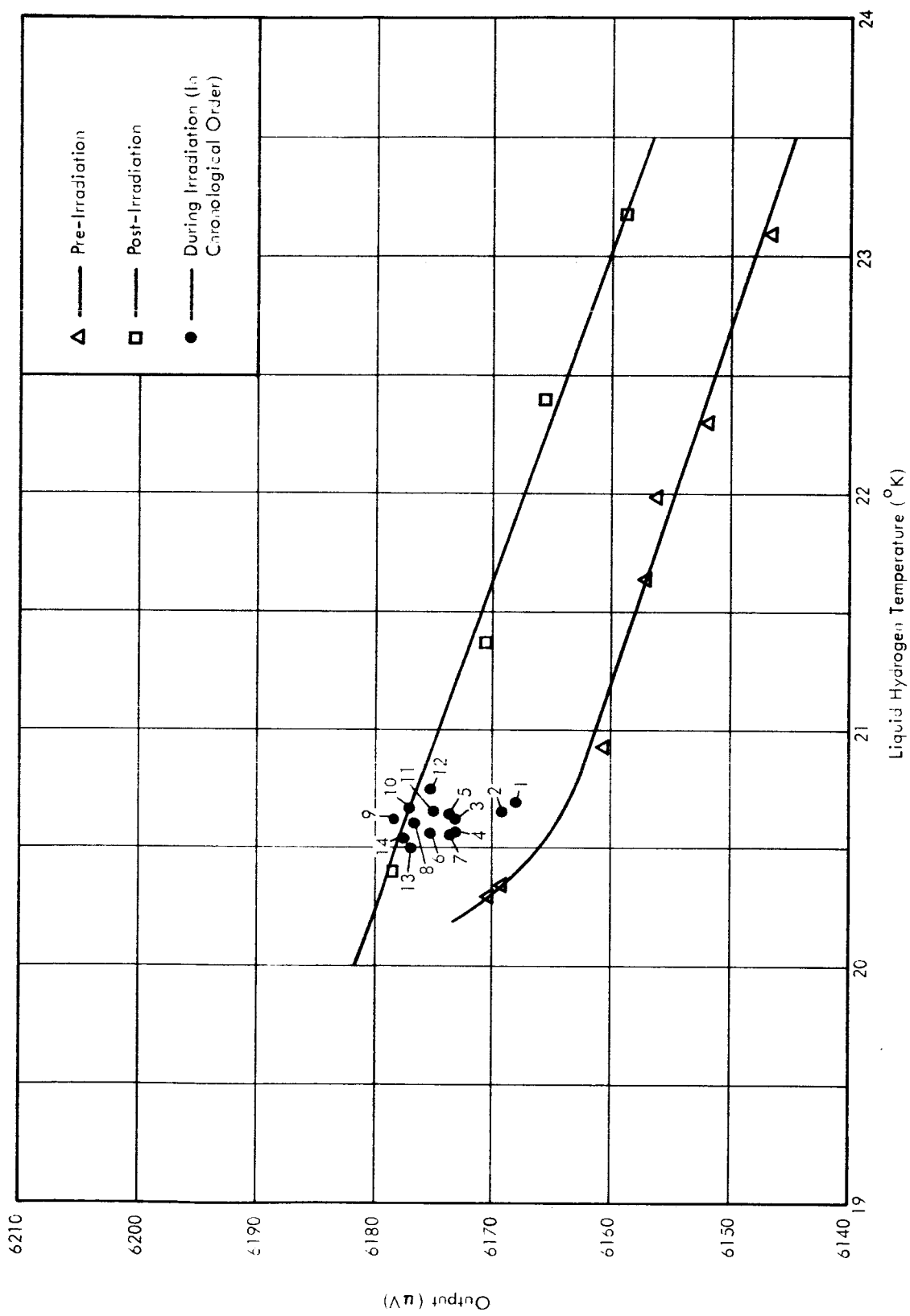


FIGURE 12 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN R5-1 VERSUS LIQUID HYDROGEN TEMPERATURE

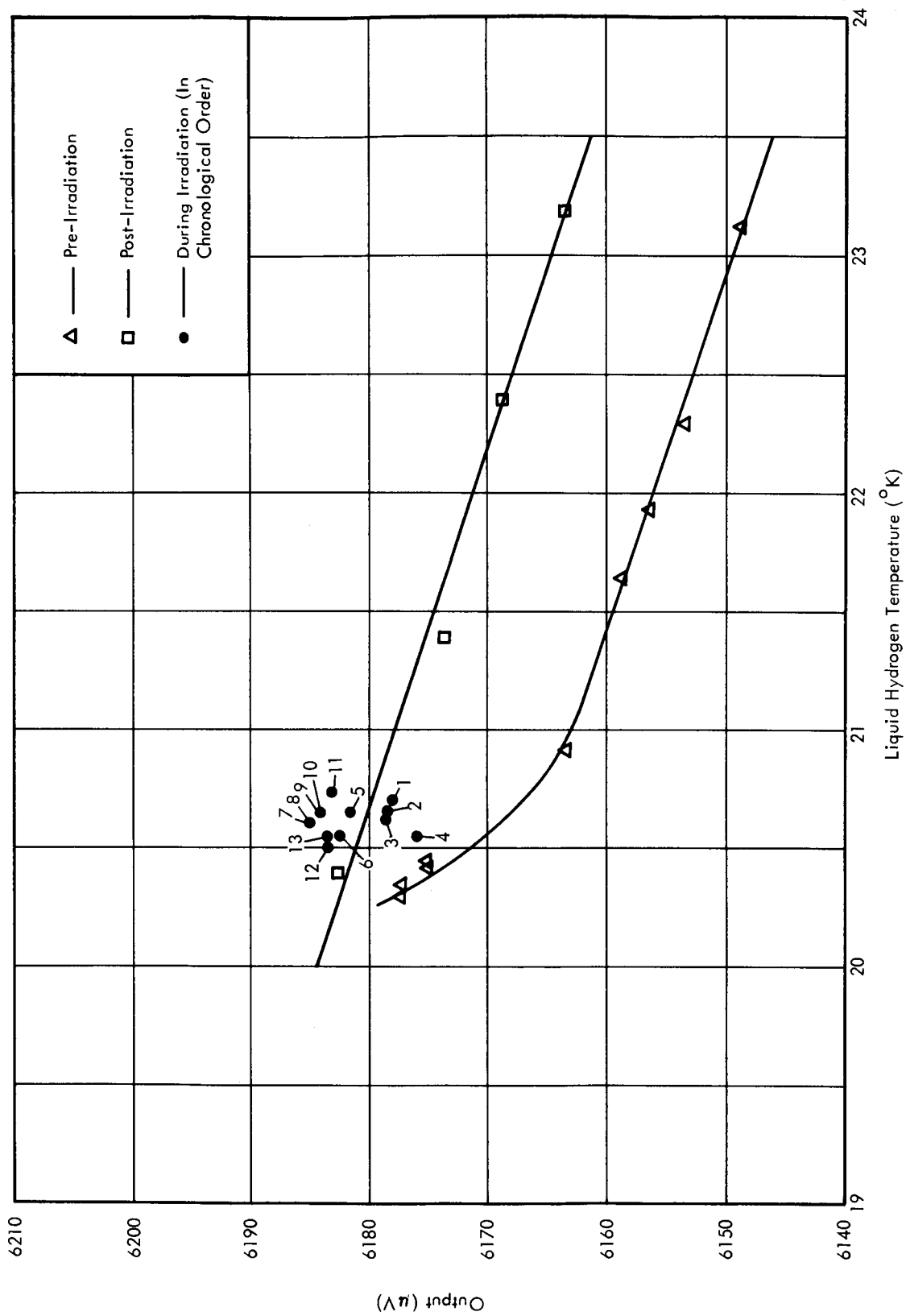


FIGURE 13 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN R5-2 VERSUS LIQUID HYDROGEN TEMPERATURE

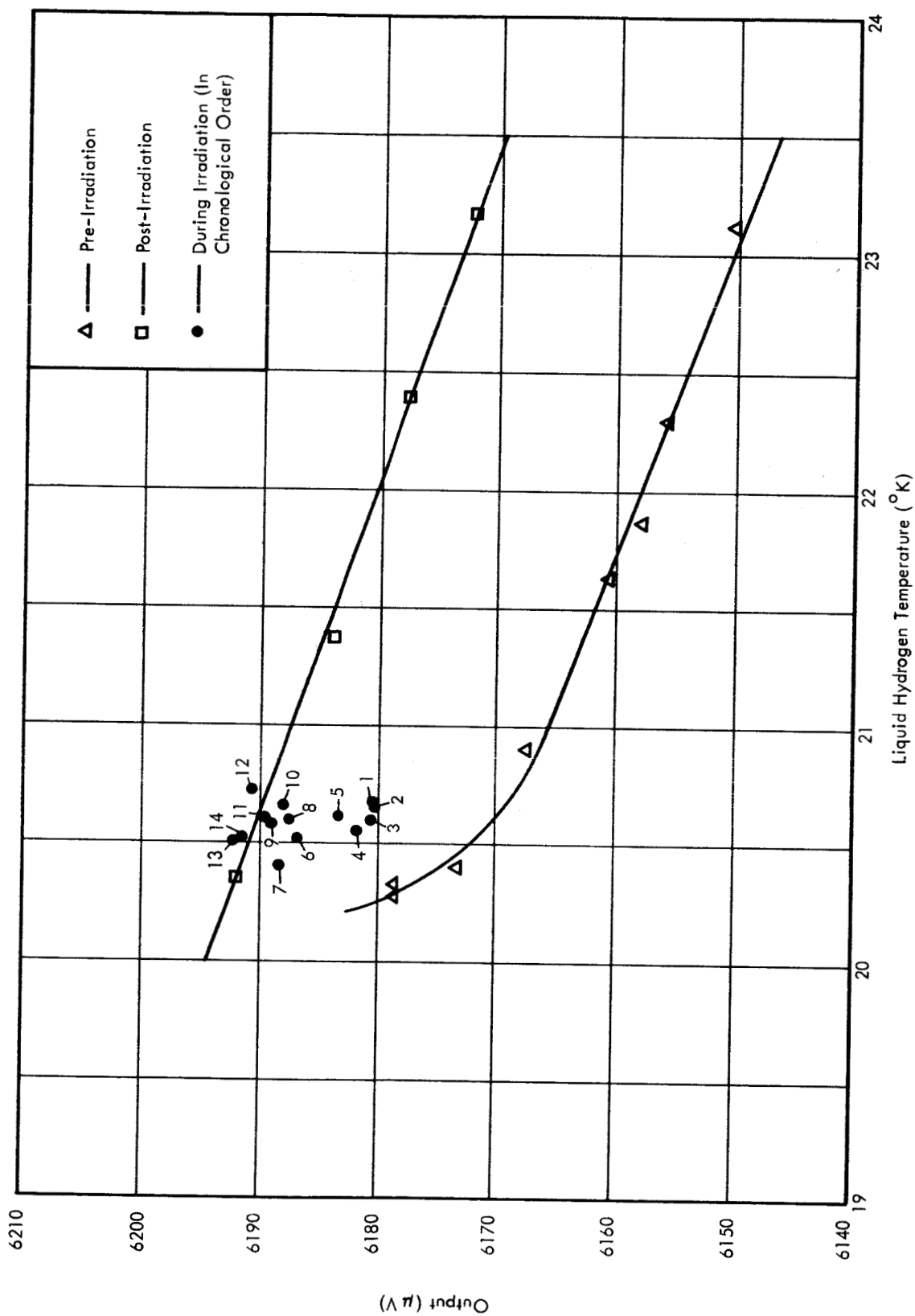


FIGURE 14 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN T-2 VERSUS LIQUID HYDROGEN TEMPERATURE

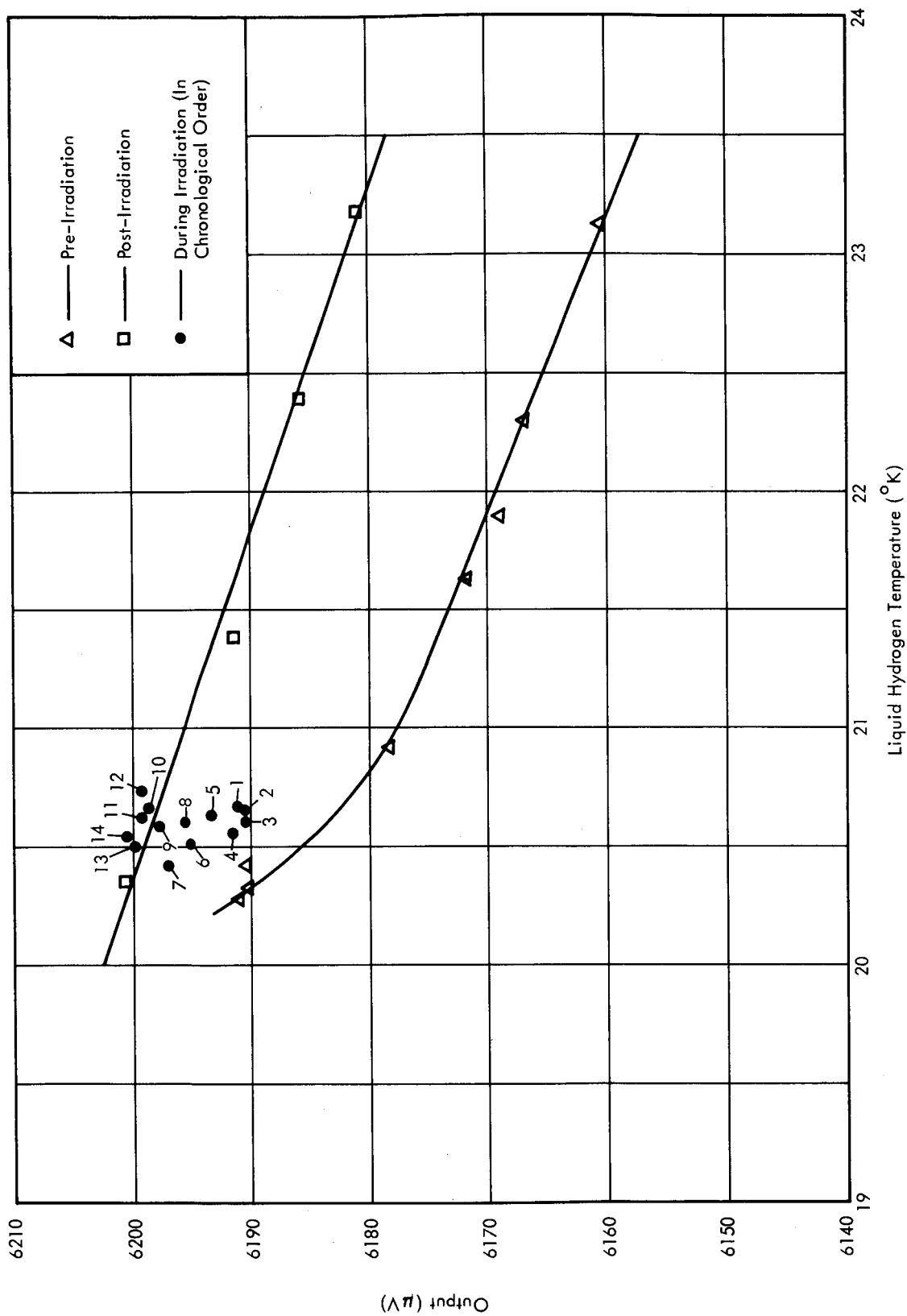


FIGURE 15 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN T-1 VERSUS LIQUID HYDROGEN TEMPERATURE

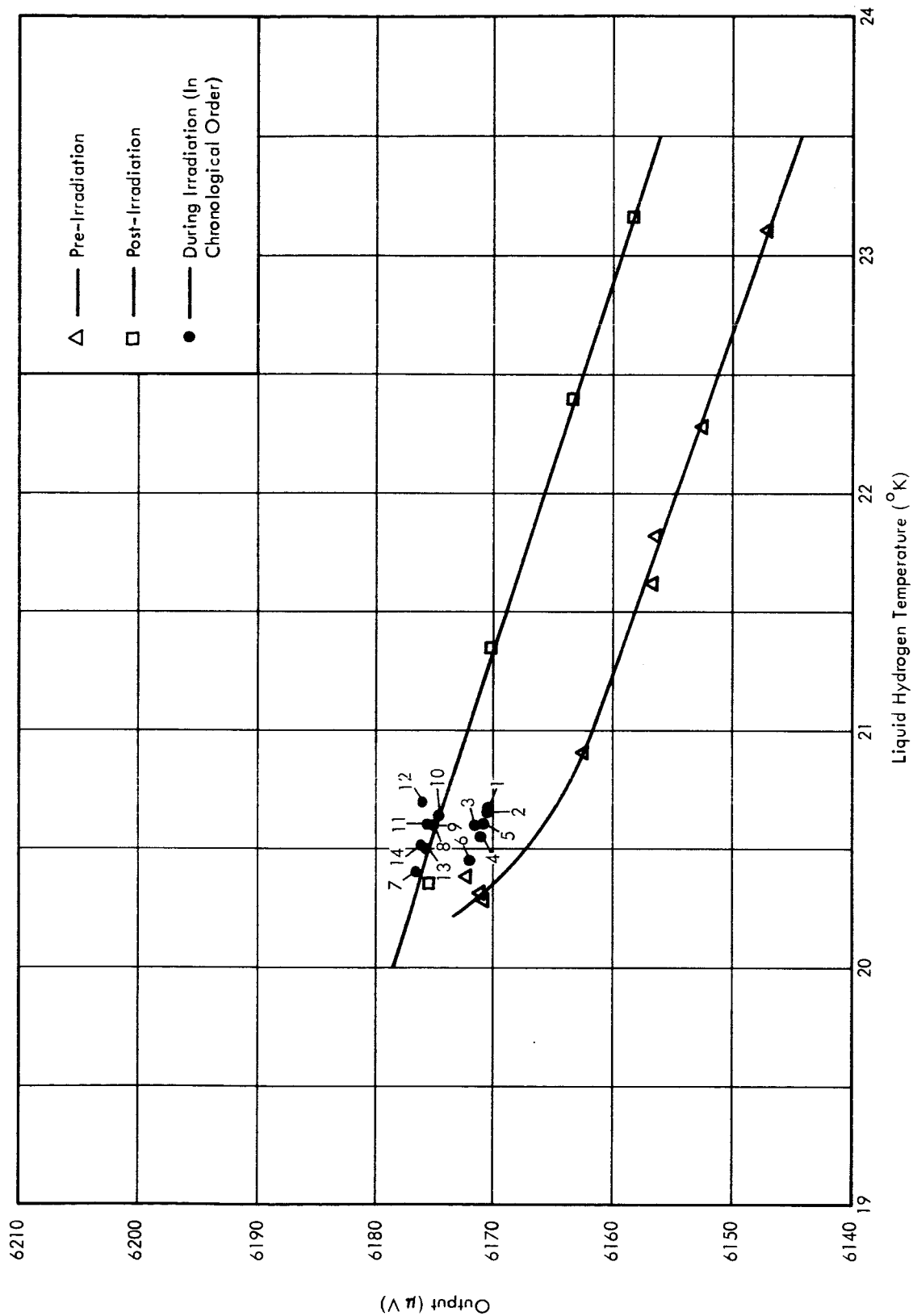


FIGURE 16 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN G-1 VERSUS LIQUID HYDROGEN TEMPERATURE

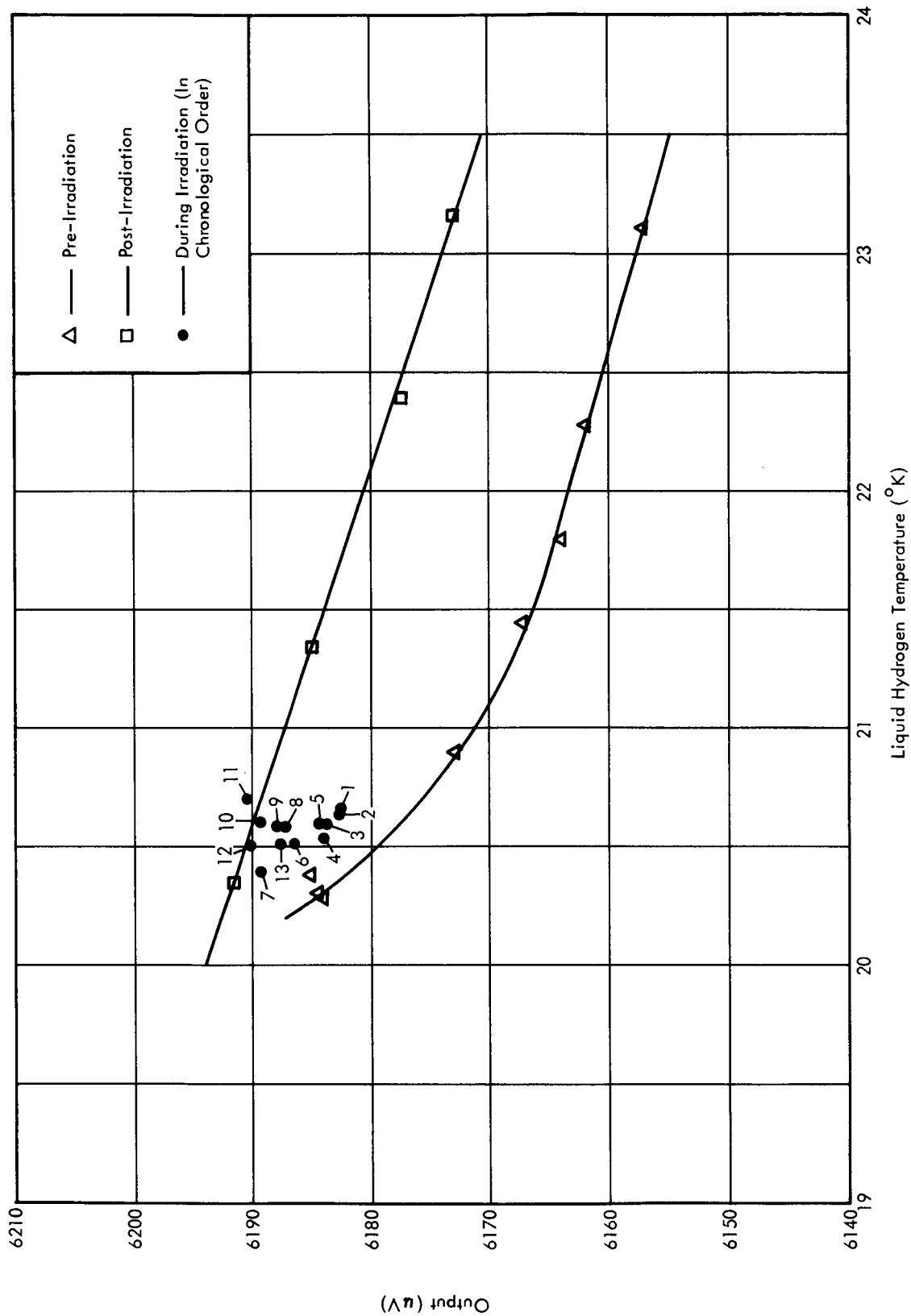


FIGURE 17 OUTPUT OF COPPER-CONSTANTAN THERMOCOUPLE ON SPECIMEN G-2 VERSUS LIQUID HYDROGEN TEMPERATURE

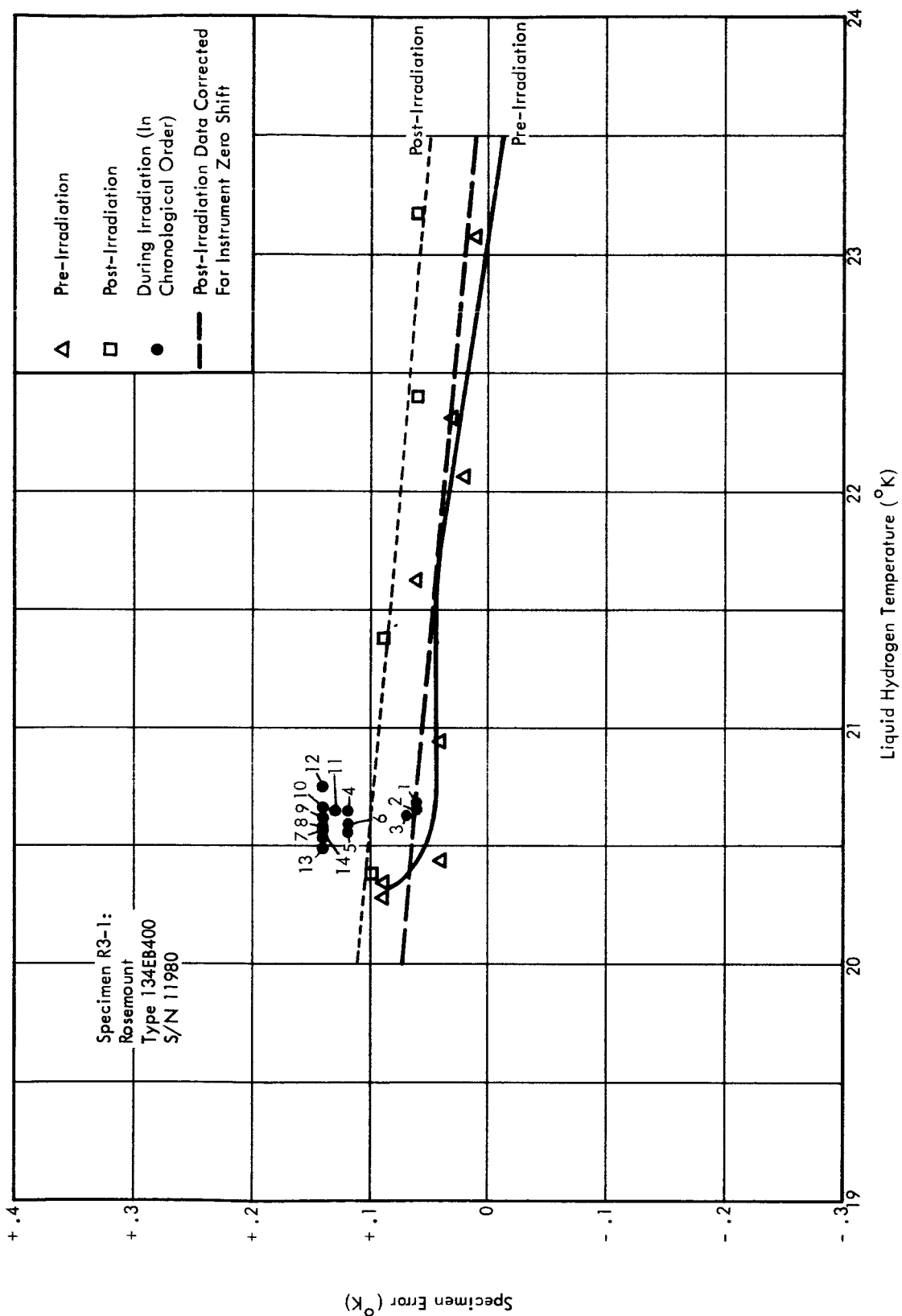


FIGURE 18 ERROR OF SPECIMEN R3-1 VERSUS LIQUID HYDROGEN TEMPERATURE

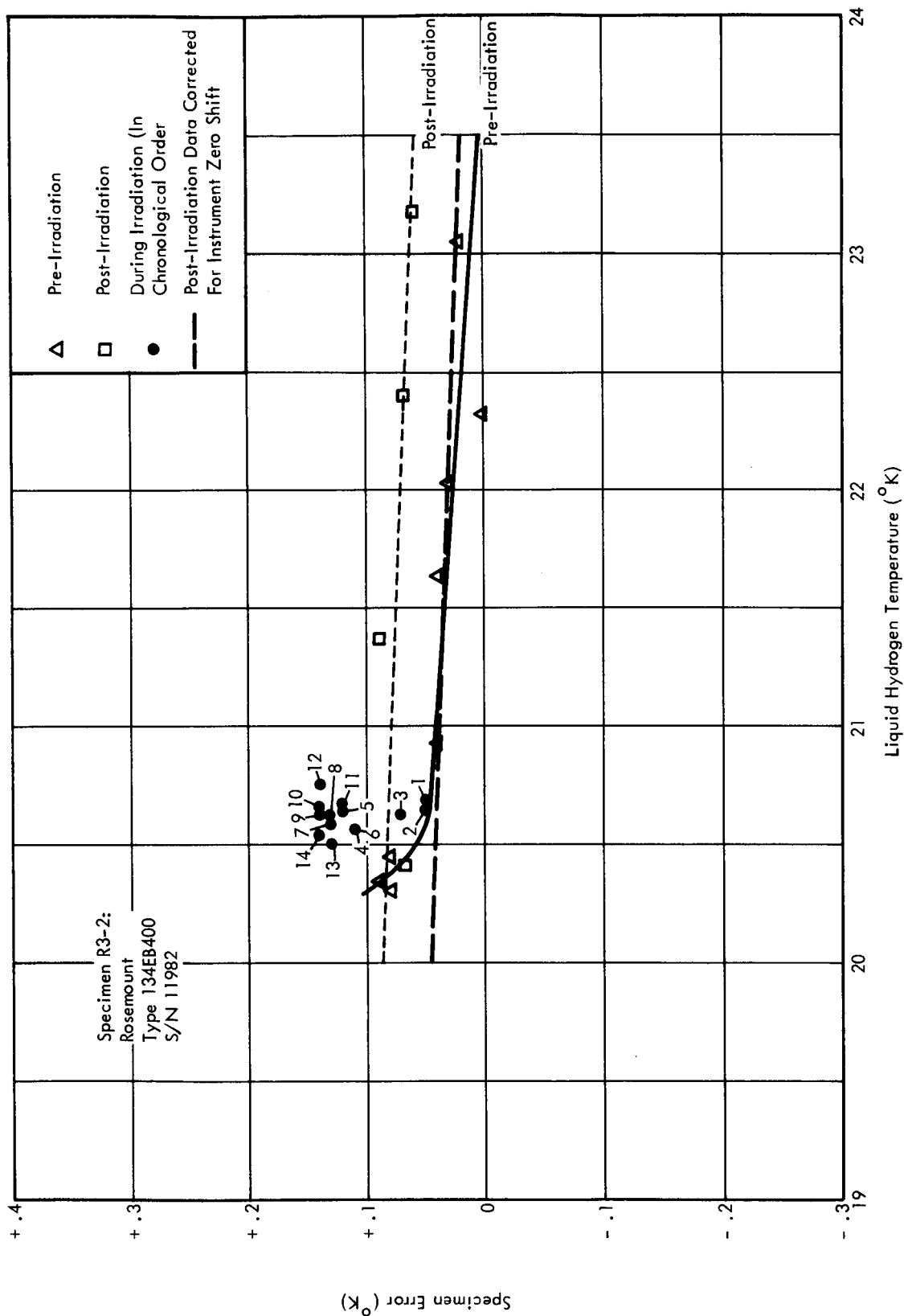


FIGURE 19 ERROR OF SPECIMEN R3-2 VERSUS LIQUID HYDROGEN TEMPERATURE

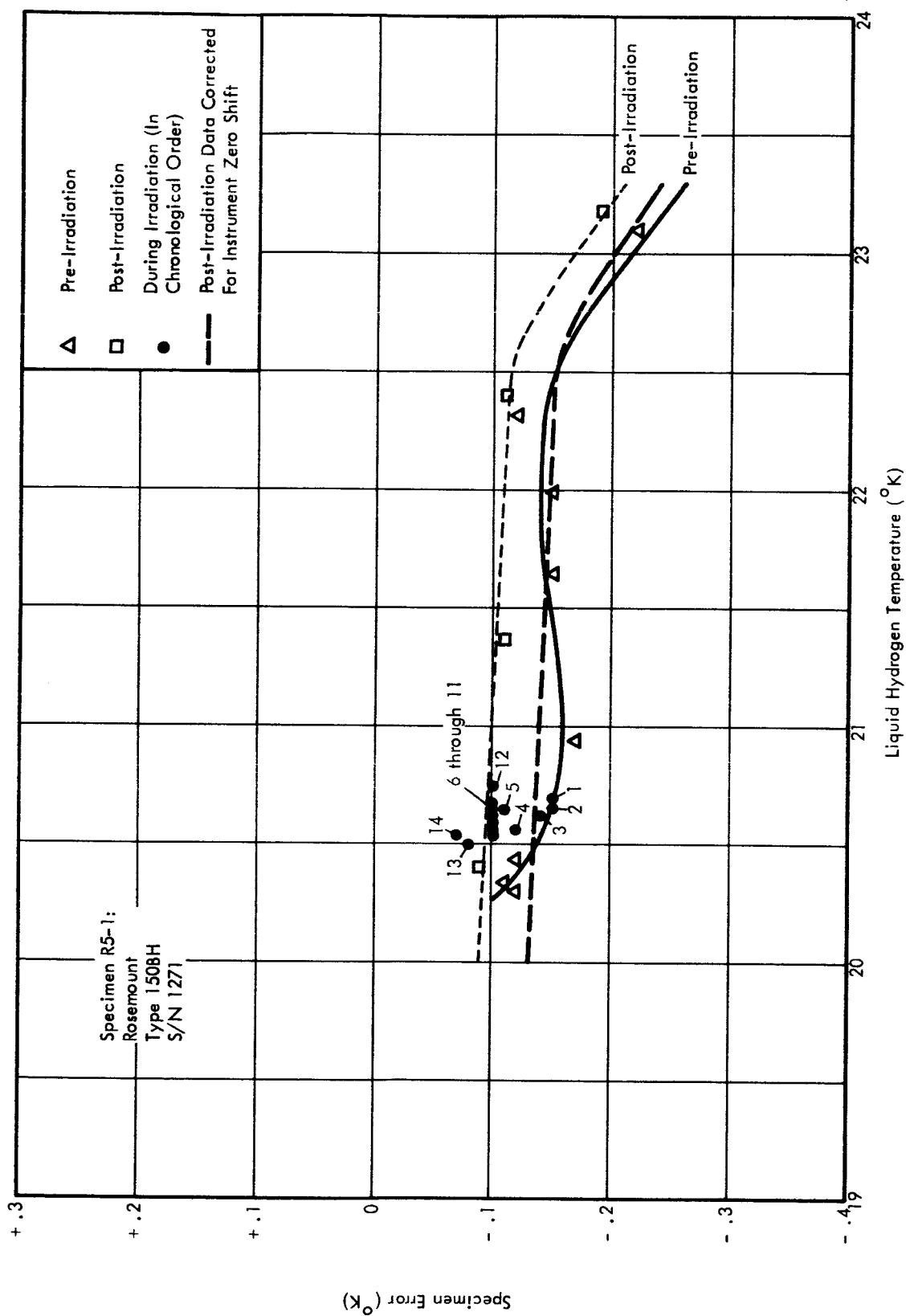


FIGURE 20 ERROR OF SPECIMEN R5-1 VERSUS LIQUID HYDROGEN TEMPERATURE

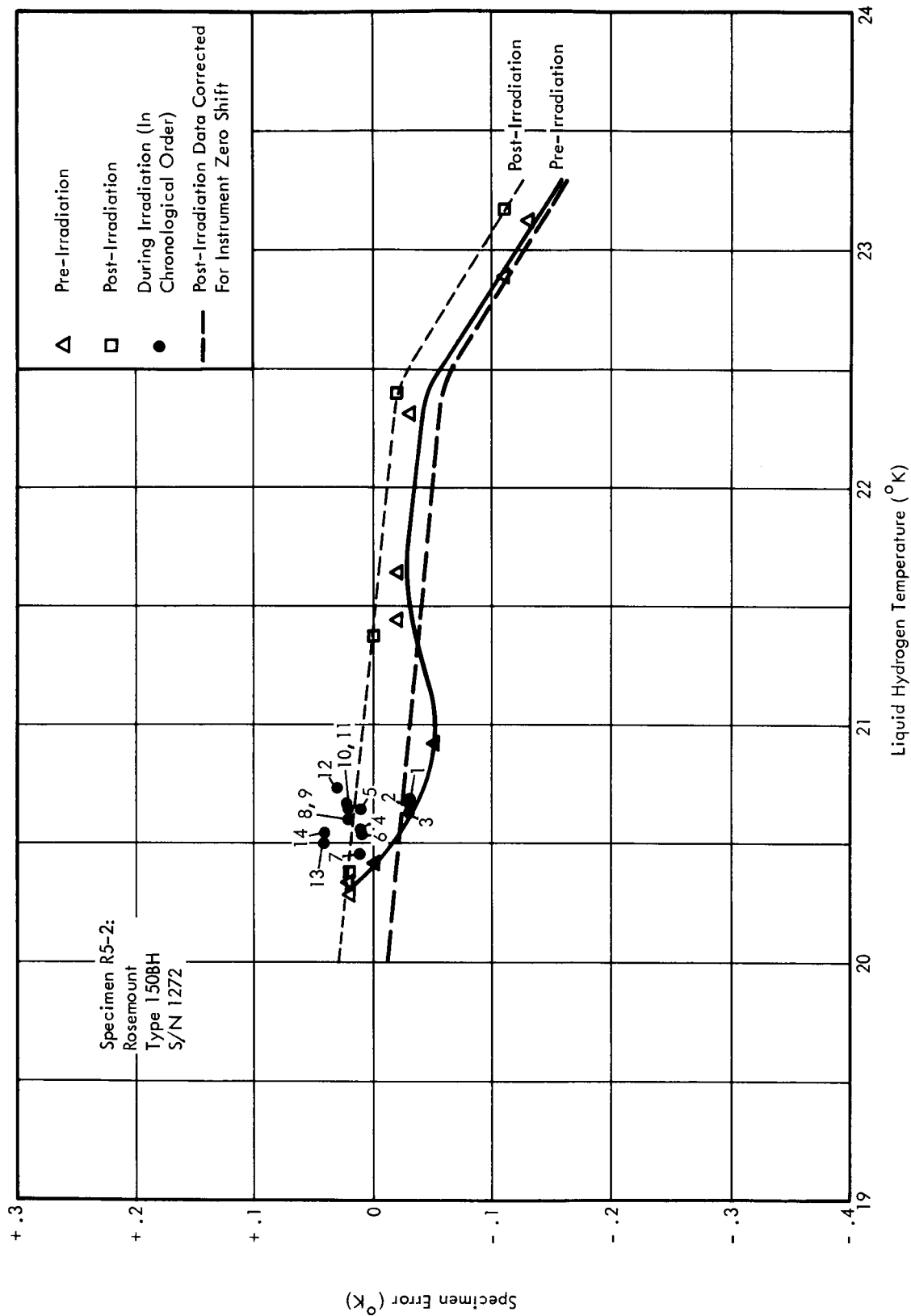


FIGURE 21 ERROR OF SPECIMEN R5-2 VERSUS LIQUID HYDROGEN TEMPERATURE

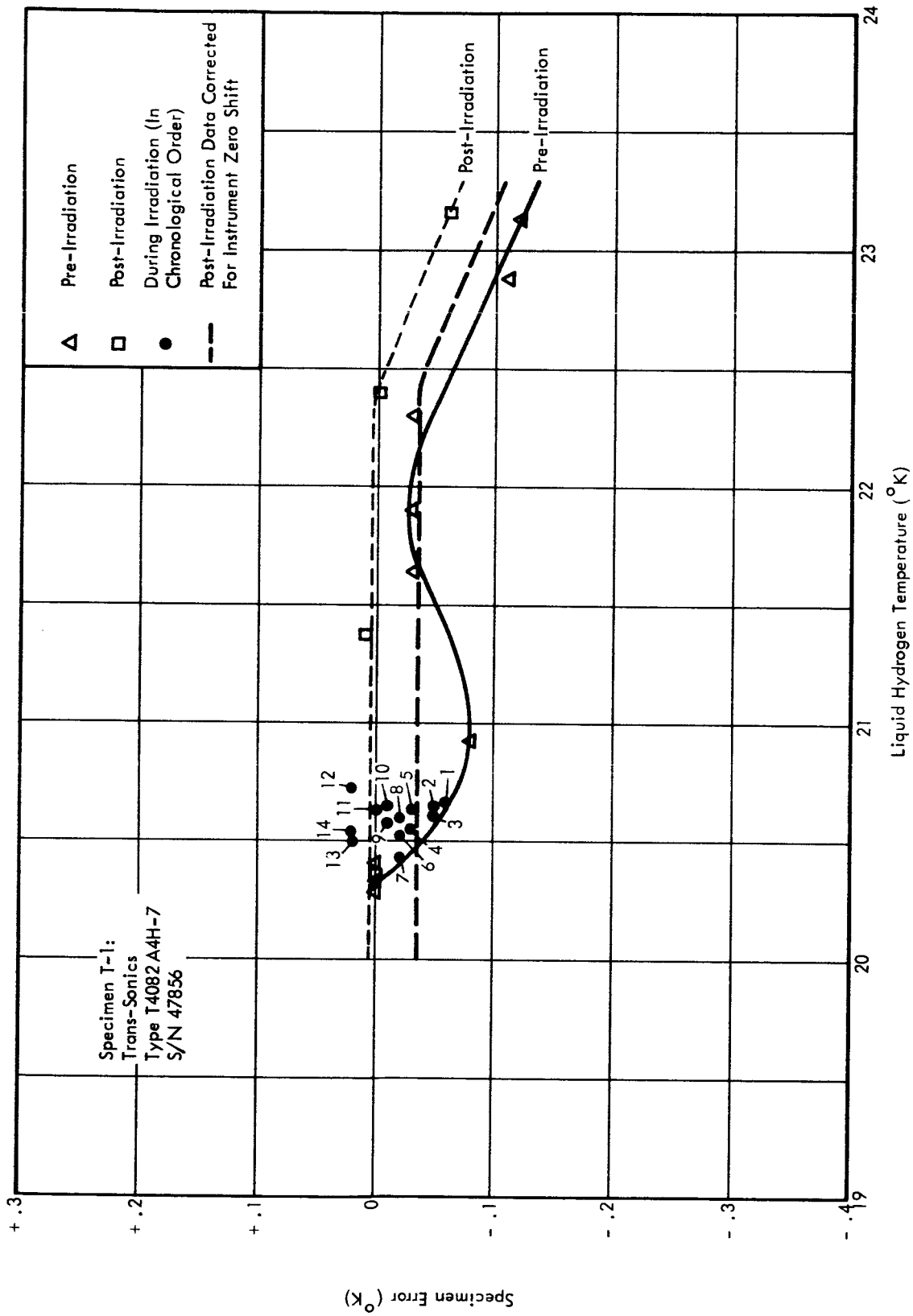


FIGURE 22 ERROR OF SPECIMEN T-1 VERSUS LIQUID HYDROGEN TEMPERATURE

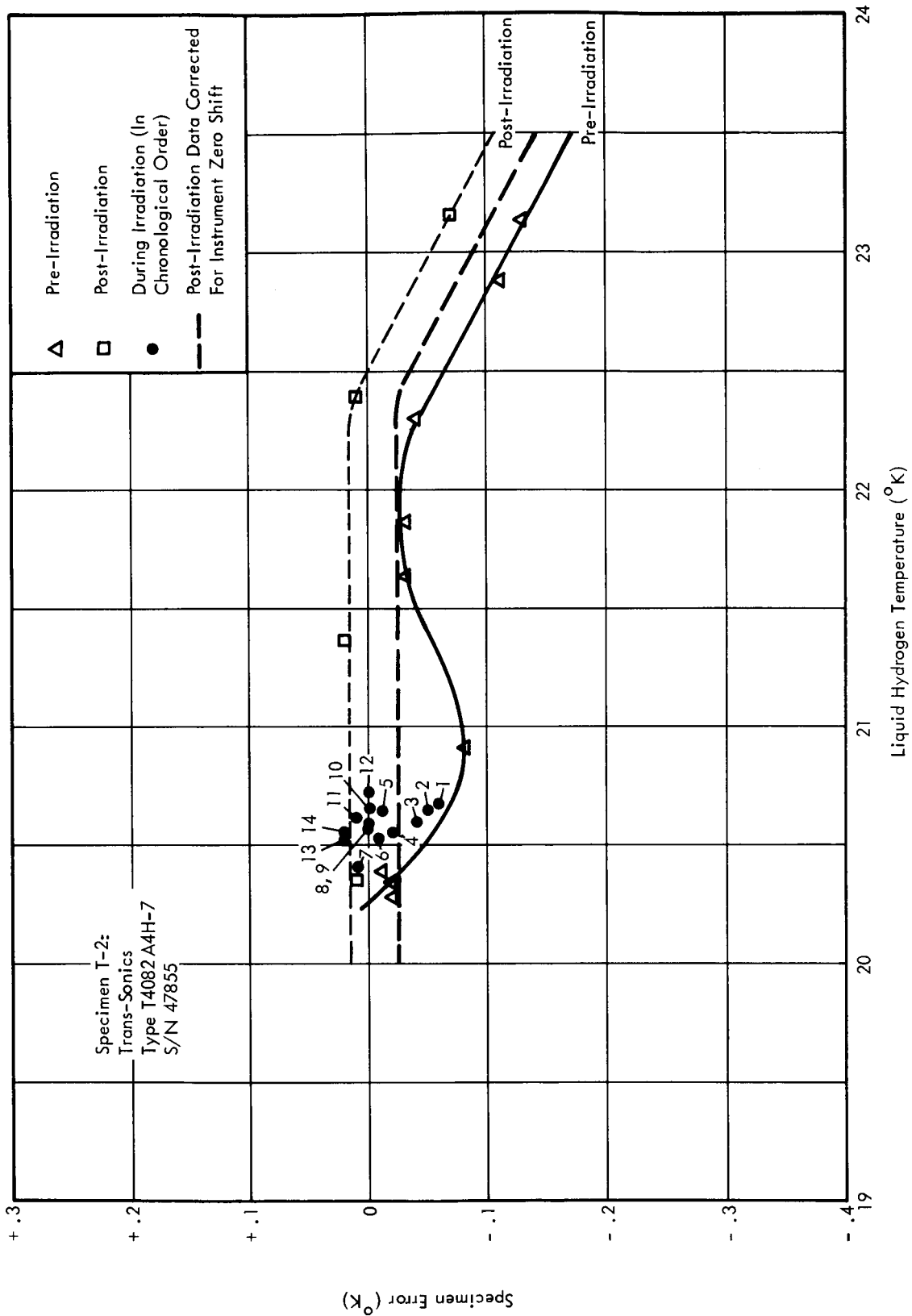


FIGURE 23 ERROR OF SPECIMEN T-2 VERSUS LIQUID HYDROGEN TEMPERATURE

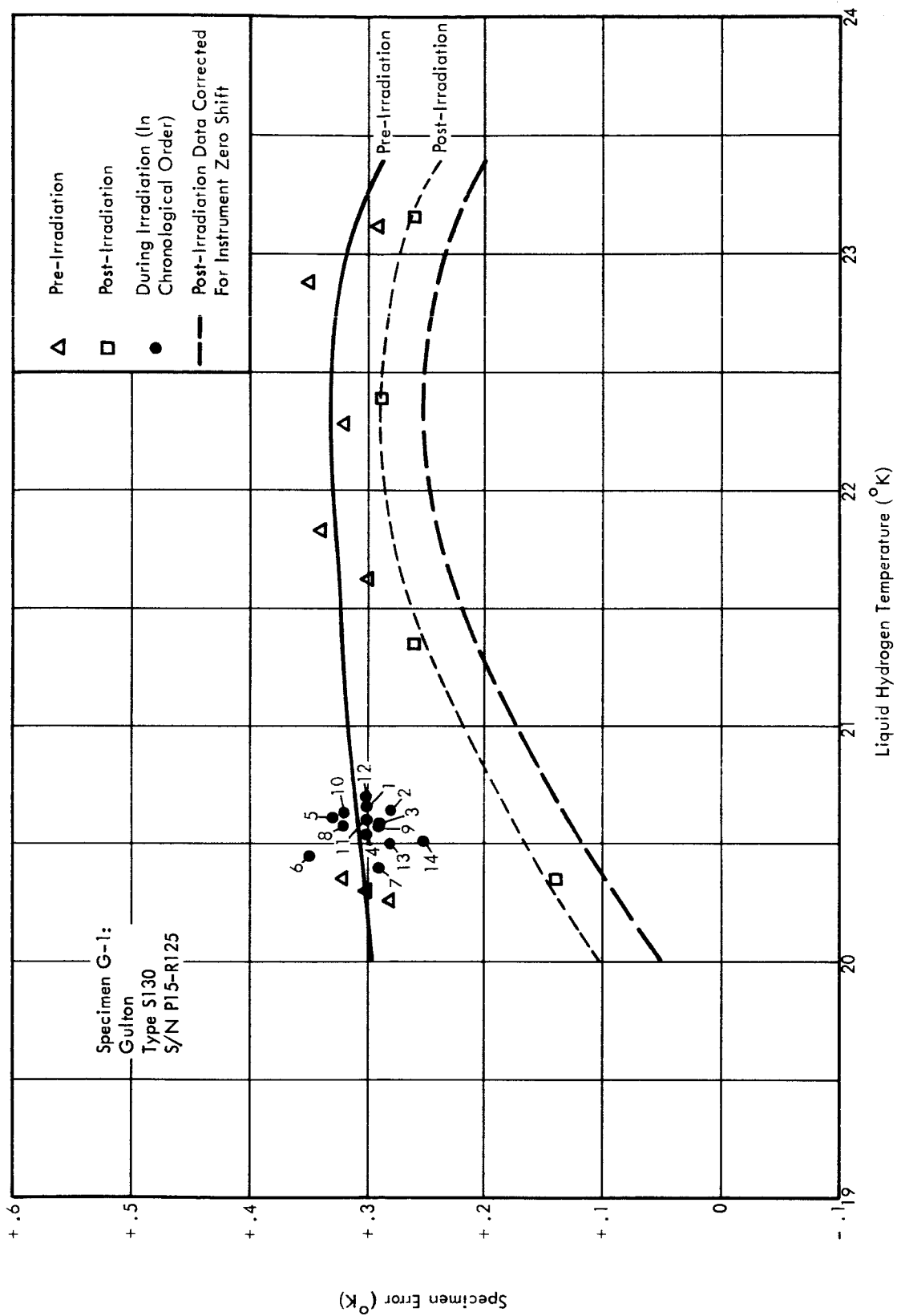


FIGURE 24 ERROR OF SPECIMEN G-1 VERSUS LIQUID HYDROGEN TEMPERATURE

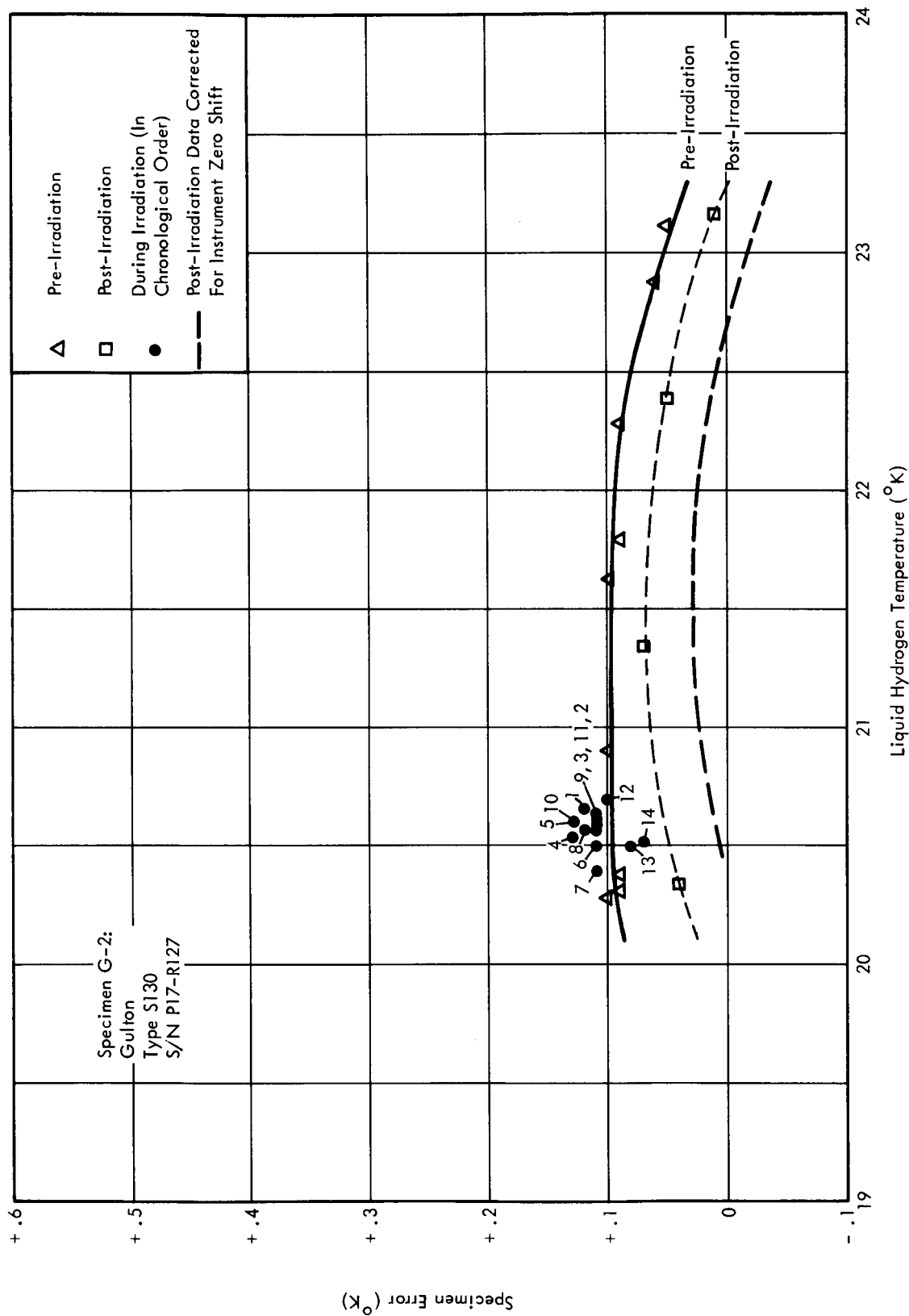


FIGURE 25 ERROR OF SPECIMEN G-2 VERSUS LIQUID HYDROGEN TEMPERATURE

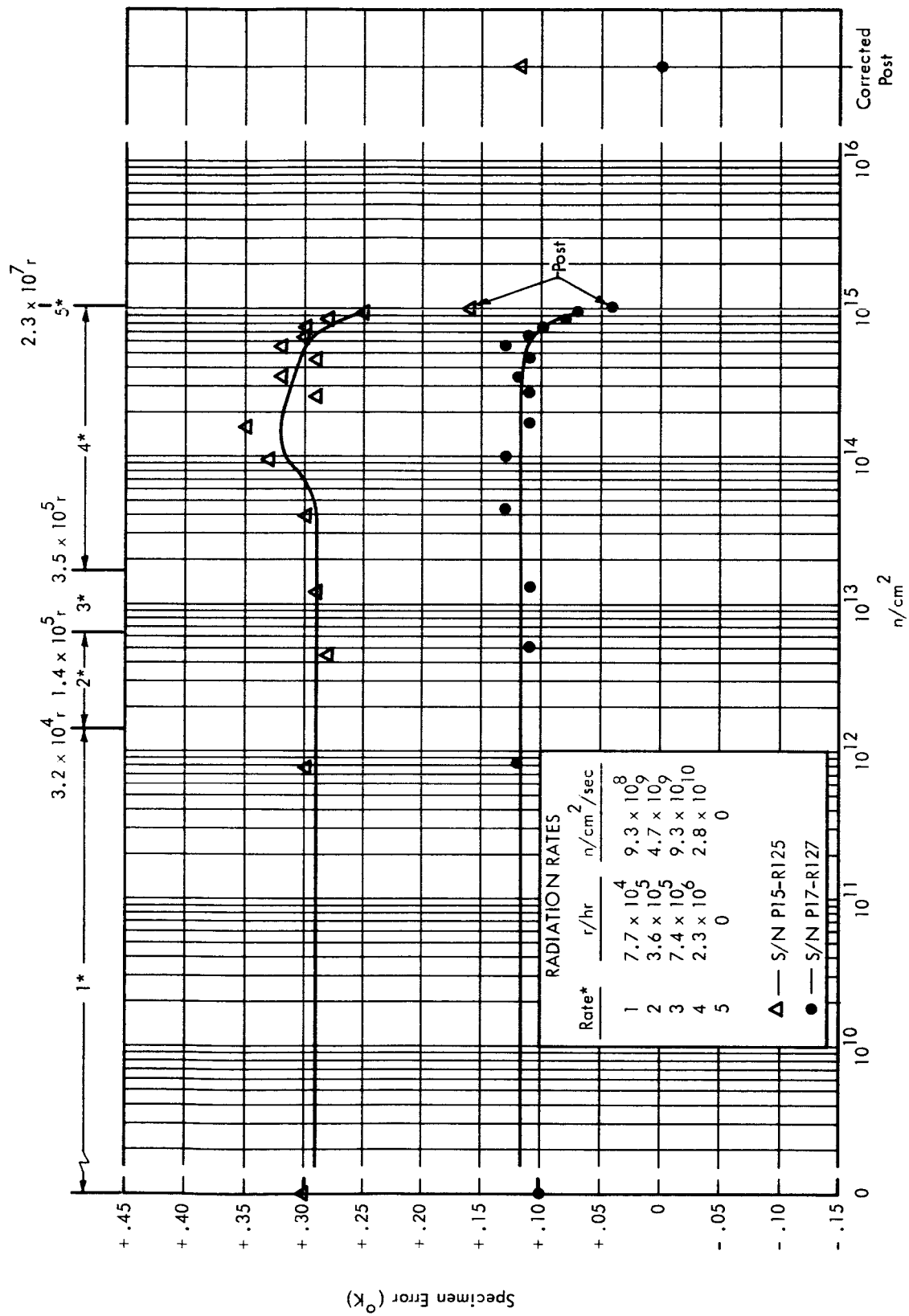


FIGURE 26 GULTON CARBON RESISTANCE THERMOMETERS, TYPE S130; SPECIMEN ERROR AT ABOUT  $20.5^{\circ}\text{K}$  VERSUS INTEGRATED NEUTRON FLUX